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Thermal Control of Power Supplies with Electronic Packaging Techniques

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THERMAL CONTROL OF POWER SUPPLIES WITH ELECTRONIC PACKAGING TECHNIQUES

Approved

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FOREWORD

This report was prepared by the Martin Marietta Corporation, Denver Division, under Contract NAS8-31799, "Thermal Control of Power Supplies with Electronic Packaging Techniques (Heat Pipe Technology)" for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration.

ABSTRACT

This report summarizes analysis, design, and development by the Martin Marietta Corporation to reduce the weight and size of a NASA candidate standard modular power supply with a 350-watt output. By integrating low-cost commercial heat pipes in the redesign of this power supply, weight was reduced 44% from that of the previous design. Part temperatures were also appreciably reduced, increasing the environmental capability of the unit. A complete 350-watt modular power converter was built and tested to evaluate thermal performance of the redesigned supply.

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I. INTRODUCTION

In its continuing effort to reduce cost associated with space hardware development and production, Marshall Space Flight Center (MSFC), in conjunction with the other NASA agencies, is developing various standard items of equipment that show promise of significant savings in development dollars for use on up-coming space missions. Among these items is a multiple output power converter capable of satisfying a large percentage of the future load power requirements for NASA space applications. This Standard Load Center Converter (SLCC) is a modular unit with multiple output voltages which can be tailored to meet specific mission requirements with minimum development cost and risks. MSFC has completed the requirements definition, design, breadboarding and testing of the electronic circuitry and has had a prototype 350-watt unit built for evaluation.

Under contract with Martin Marietta, this prototype converter was repackaged for space flight application using heat-pipes to achieve more efficient thermal control and significant weight and volume savings.

Recent developments in heat-pipe technology and materials engineering have suggested heat pipes for increasing packaging efficiency by more efficient removal of internally generated heat. Their use improves performance and reduces size and weight, enabling increasingly complex vehicles to perform deep space exploration. These devices are available from several sources and have a proven history of reliable performance and long life. They have been used in Skylab and DOD satellite systems where concentrated heat loads had to be handled efficiently with minimum size and weight impact.

This report describes the evaluation and repackaging of the NASA prototype 350-watt converter to reduce weight and size and improve thermal performance under typical spacecraft environmental conditions. With these improvements, this candidate Standard Load Center Converter should find broad application in future NASA space missions. It will provide major savings in hardware development costs through its availability and use as a standard component for power conditioning.

II. PROTOTYPE POWER SUPPLY PACKAGING EVALUATION AND REDESIGN APPROACH

Having established the general design requirements and circuit implementation for a candidate standard modular power supply, MSFC, in conjunction with Teledyne Brown Engineering, produced a prototype 350-watt unit which was evaluated for performance characteristics and considered applicable for use on many future NASA programs. The development and test results are contained in Final Report EE-MSFC-1888.

Under this contract, Martin Marietta was given the task of evaluating and improving the packaging design by reducing size and weight and assuring reliable performance in the thermal and dynamic environments typical of space hardware applications. As design goals, the prototype power supply volume was to be reduced 30% and the weight should not exceed 15 lb (6.8 kg).

The first phase of this design study was to evaluate and redesign the prototype packaging configuration and to furnish MSFC a thermal analysis of the revised design. An initial prototype evaluation and partial redesign, performed under contract NAS8-28956 by Martin Marietta, pointed out specific thermal problems and areas where weight and size reductions might best be accomplished. That information is contained in Final Report MCR-75-389 and reiterated in part in this document for the reader's convenience.

A. PROTOTYPE THERMAL ANALYSIS AND PACKAGING EVALUATION

The prototype NASA power supply constituting the baseline design for the Martin Marietta study, is shown in Figure 1. The assembly consists of four physically identical pulse-width-modulated switching regulators capable of delivering a total of 350 W at approximately 80% efficiency. The isolated outputs adaptable to operate from 4 to 108 Vdc were built to deliver the following powers and voltages:

50 W at +5 Vdc
100 W at +15 Vdc
100 W at -15 Vdc
100 W at +28 Vdc

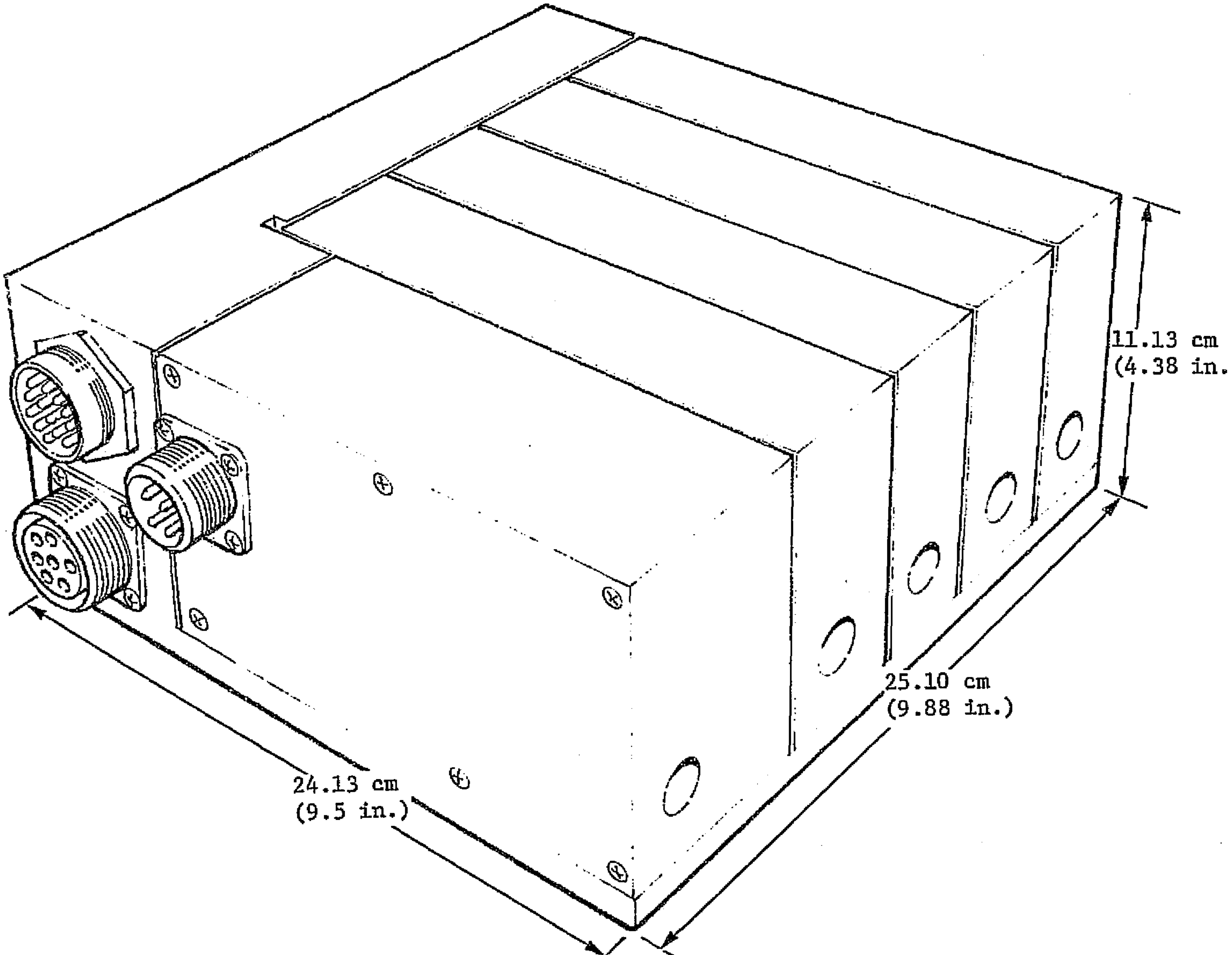

Figure 1 NASA Prototype 350-W Power Supply

An input module, somewhat larger than the others, contains the input filter circuits and a housekeeping supply consisting of four isolated +15-V outputs, clock signals required by each of the regulator modules, failure monitoring circuitry for detection and identification of failure conditions on the input power line, and buffer circuits for the overvoltage and undervoltage detectors in the output regulators. As shown in Figure 1, the five modules are mounted on a plate structure and interconnected by a main-frame distribution chassis. Under full load, the power supply dissipates 98.4 W, most of which is distributed to spacecraft supporting structure via the module carrier baseplate. Thermal dissipation breakdown is:

Input Module (A1)	23.8 W
+5-V output regulator (A2)	13.7 W
+15-V output regulator (A3)	21.1 W
-15-V output regulator (A4)	21.1 W
+28-V output regulator (A5)	18.7 W

In accordance with Phase I of the study contract, a detailed thermal analysis was performed on this baseline design. Environmental temperatures taken from study predictions for Space Tug were considered to represent a typical application for this power supply. In the Tug mission, the temperature extremes are:

Isothermal panel (spacecraft equipment mounting surface)	+4.4 to 32.2°C
Radiation environment	-173 to +22°C

A mathematical model was devised to represent physical interrelationships in terms of conductivity, surface finish, view factors, and internal heat generation. Internal temperatures were computed for 371 nodes. Table 1 summarizes some of these results.

Analyses results show marginal or excessive temperatures at several places in the power supply, especially in the input module, where the combination of high power dissipation of printed circuit (PC) board-mounted parts and inadequate thermal paths to the baseplate resulted in temperatures above 160°C. This temperature prediction is for the maximum average PC-board temperature under hot ambient environmental conditions. Excessive case temperatures were also predicted for capacitors and chokes embedded in the input filter module in the input module assembly.

The output regulator modules exhibited better temperature control, with relatively few instances of marginally hot conditions for circuit-board-mounted parts.

Table 1 Baseline-Design Temperature-Prediction Summary

	Ref Desig	Dissipation, W	Predicted Temperatures, C° (F°)	
			Hot Ambient	Cold Ambient
INPUT MODULE A1				
PC Board	A1	2.046	163 (325)	152 (306)
PC Board	A2	2.046	171 (340)	161 (322)
PC Board	A4	4.123	173 (343)	163 (325)
Filter	FL1	1.6	60 (140)	31 (88)
Filter	FL2	1.6	58 (136)	29 (84)
Transformer	T1	0.6	52 (126)	23 (73)
Transistor	Q1	7.9	58 (136)	30 (86)
Input Filter:	A5			
Choke	L3	1.2	107 (225)	79 (174)
Choke	L2	1.2	106 (223)	78 (172)
Choke	L1	1.2	99 (210)	71 (160)
Capacitors	C1→C4	0.8	102 (216)	74 (165)
OUTPUT MODULE A3				
PC Board	A1	2.173	80 (176)	58 (136)
PC Board	A2	0.956	72 (162)	48 (118)
Transistor	Q1	4.56	63 (145)	34 (93)
Transistor	Q2	4.65	59 (138)	31 (88)
Transformer	T1	0.15	56 (133)	28 (82)
Transformer	T2	0.15	54 (129)	26 (79)
Transformer	T3	1.8	59 (138)	31 (88)
Choke	L1	0.95	56 (133)	27 (81)
Diode	CR1	2.8	74 (165)	46 (115)
Diode	CR2	2.8	74 (165)	46 (115)

A review of the overall prototype packaging has led to the following conclusions:

1) Output regulator packaging density is nearly optimum, considering part geometry, cost factors related to fabrication and assembly, and thermal and structural requirements. About 85% of the enclosed volume is structure, parts, wiring, or clearance space. Attempts to repackage existing circuits saved little volume, without resorting to expensive high-density packaging for PC-board-mounted parts.

2) The input module could be repackaged with some volume savings because it contains spare room for PC boards and unused chassis volume. Because of excessive temperatures predicted by the thermal analysis, any redesign must lower the temperatures by redistributing major dissipators and better heat sinks.

3) The carrier baseplate to which the modules and main-frame chassis are bolted distributes structural and thermal loads to the power supply/spacecraft mounting interface. The plate is machined with numerous grooves or slots on its outside surface, which improves conduction to the air for ground operation and reduces the weight of the 0.98-cm (3/8-in.) plate. However, its structural and thermal load-distribution efficiency is poor from a weight standpoint, especially for spacecraft applications. By combining the main frame with the carrier plate in a manner that minimized thermal gradients from the spacecraft structure to power supply modules, a significant weight savings might be realized without penalizing thermal performance.

4) With the placement of modules and main frame over the carrier plate, it is necessary to disassemble the power supply to bolt the carrier to its spacecraft mounting surface and then reattach the modules individually. This is an unnecessary burden on spacecraft integration and increases the probability of inadvertent interchange of output modules or improper alignment of the modules as installed on the spacecraft. For spacecraft integration and maintainability, a mounting scheme in which the power supply assembly represents the lowest replaceable unit (LRU), with shop-replaceable individual modules, appears to be more desirable.

B. REPACKAGING APPROACH

From the prototype evaluation, two modifications to the power supply design appeared to show the most promise in attaining the objectives of reduced weight and size. First, by seeking more efficient heat removal techniques for the major dissipators, the module structural design might be optimized. Secondly, by integrating the input module circuits, power distribution filtering functions and supporting structure into one main-frame chassis, the packaging efficiency could be significantly improved with resulting weight and volume reductions.

In assessing the first item (improved thermal efficiency), it was noted that most of the dissipated thermal energy originates from three sources: output transistors and diodes, and output magnetics which are characteristic of transistor switching power regulators. For the 15-V output regulator, some 18 W, or about 86% of the total dissipated power under full load conditions, comes from these sources. Other parts in the control logic, driver, and error amplifier circuits are insignificant dissipators. The usual practice is to chassis mount the major dissipators. This provides a high-conductance path to some ultimate heat sink, which in most cases entails additional metal for heat transfer beyond that required solely for structural purposes, thus incurring a weight burden for thermal reasons.

When using heat pipes, careful attention must be given to obtaining a low thermal impedance at heat pipe interfaces: thus, getting the heat into and away from the device efficiently. For this specific power supply application, a saddle arrangement (Figure 2a) was devised for effecting a low thermal impedance between the TO-3 transistor case and the heat-pipe evaporator. The particular geometry of the TO-3 case, with its base and emitter leads positioned asymmetrically, allowed sufficient room for close coupling the transistor and heat pipe via the saddle arrangement. A similar scheme was used for coupling the stud-mounted power diodes to the heat pipes (Figure 2b).

C. HEAT-PIPE OPERATION

To emphasize its simplicity and inherent potential for reliable space applications, a brief discussion of heat-pipe operation is

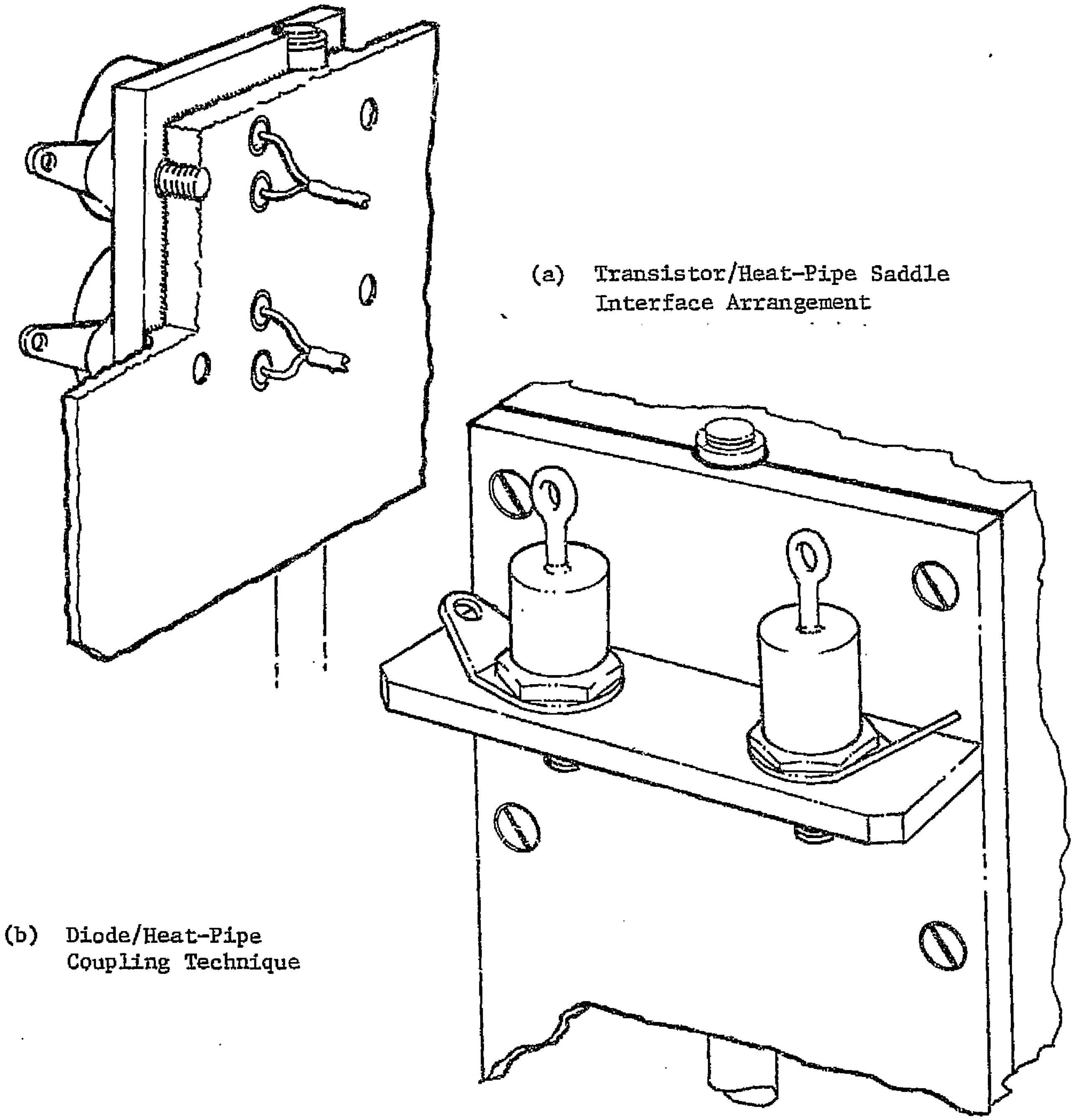

Figure 2 Heat-Pipe Dissipator Mounting Techniques

offered. The basic heat-pipe structure (Fig. 3) consists of a sealed tubular container enclosing a wick structure for capillary flow of the liquid added to saturate the wick. With the application of heat, some liquid vaporizes and flows to a cooler region, where it condenses. The wick returns the condensate through capillary pumping action. Evaporation, condensation, and pumping of the liquid in a capillary wick are used to continuously transfer latent heat of vaporization from one region to another without external aids. Furthermore, due to the heat pipe's uniform construction, it doesn't matter which region is used for evaporation or condensation.

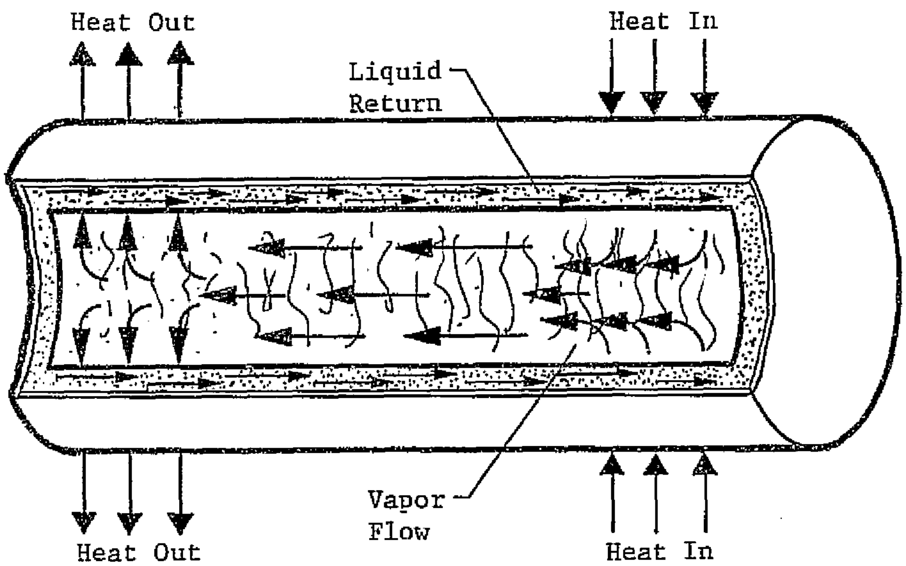

Figure 3 Basic Heat-Pipe Structure

The process is essentially isothermal for moderate lengths because the vapor pressure drop between the evaporator and condenser is small. With a properly designed heat pipe, the temperature gradient between the heat source and heat sink can be very low, especially when compared with solid-metal conduction methods. Conduction of the 0.64-cm (0.250-in.) diameter heat pipe considered for integration in the modular power supply design is about 20 times greater than that of a solid copper rod of the same size, yet weighs only about one-fourth as much.

Depending largely on the compatibility of materials employed, heat pipes are potentially very reliable devices. For the power supply application, we selected a heat pipe constructed of 300 series stainless-steel, a stainless-steel felt wicking structure, and methanol working fluid. Heat pipes using this combination of materials have been successfully life tested by Hughes Aircraft for continuous periods of more than 22,000 hours at ~110°C and are considered prime candidates for use on current space programs. Similar constructions using ammonia as a working fluid have been operated without failure for more than 44,000 hours.[1]

Heat pipes have been successfully employed in many spacecraft applications, including the EREP S-191 experiment on Skylab and communication equipment cooling on classified DOD spacecraft. Hughes has developed a traveling-wave-tube amplifier (TWTA) under NASA Contract NAS1-10417 for use on the Space Shuttle program. It employs several stainless-steel/methanol heat pipes to advantage to distribute concentrated heat loads of 146 W to the baseplate thermal interface.[2]

Because of its inherent reliability, simplicity of operation, high thermal efficiency in terms of weight burden, and potential for low-cost production, we are confident that the heat pipe will become increasingly used to solve thermal control problems, not only in space applications, but also in Earth-bound engineering projects such as the Alaska pipeline. Here, heat pipes are being considered for maintaining the permafrost in its frozen state by controlling heat leakage from oil pipe-line support structures.

A description of the Hughes stainless steel/methanol heat pipe selected for integration with the SLCC power supply is reproduced on the following pages (Fig. 4). The ¼-in. diameter heat pipe, reduced in length to 5.20 in., was considered adequate for this purpose. The shorter length should reduce the heat pipe internal resistance slightly, thus improving its performance in this application. For space flights with zero gravity, the horizontal operation performance data can be applied for determining maximum heat transfer capability.

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[1] *Compatibility and Reliability of Heat Pipe Materials.* AIAA Paper No. 75-660, by A. Basiulis, R. C. Prager, Hughes Aircraft Company, Torrance, CA. Presented at the 10th Thermophysics Conference, Denver, CO, May 1975.

[2] *Heat Pipe System for Space Shuttle TWTA.* AIAA Paper No. 73-755, by A. Basiulis and C. M. Eallonardo, Hughes Aircraft Company, and B. M. Kendall, NASA Langley Research Center. Presented at the 8th AIAA Thermophysics Conference, Palm Springs, CA, July 1973.

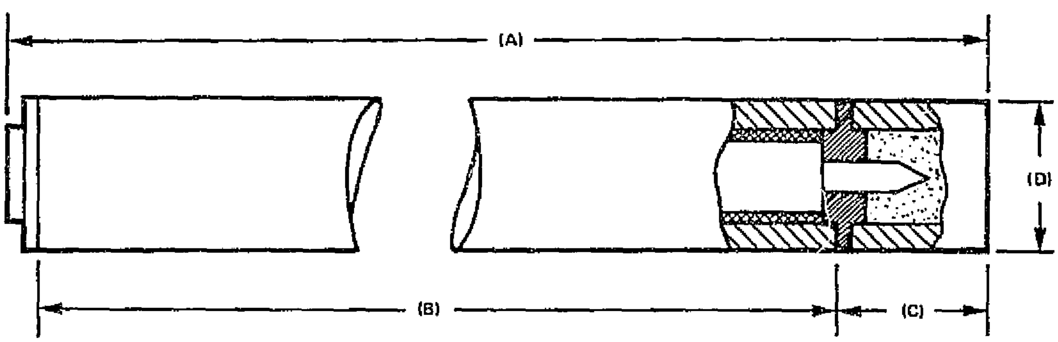
THERMAL CHARACTERISTICS

	Diameter (in.) 3/16	1/4	1/2	
Thermal Transport Capacity				
Evaporator 90° Below Condenser	55	75	180	W maximum
Horizontal Operation	17	25	60	W maximum
Evaporator 90° Above Condenser	6	10	20	W maximum
Thermal Resistance	0.85	0.55	0.42	°C/W
Thermal Response (to equilibrium)				50 seconds (¼ inch diameter)
Temperature				
Recommended Operating Range				−40°C to +120°C
Recommended Temperature Limit				200°C
Radial Flux Density				180 W/in.²

PHYSICAL CHARACTERISTICS

Envelope Material				stainless steel
Wick Material				stainless steel
Working Fluid				methanol
Standard Active Length				6 inches
Mechanical Limits				
Torque	8	15	125	inch pounds
Bending	4	8	60	inch pounds
Tension	100	140	600	pounds
Weight	8	11	38	grams
Seal Cover (pinch-off)				thermally inactive. Caution: Do not use seal cover for mounting or support.

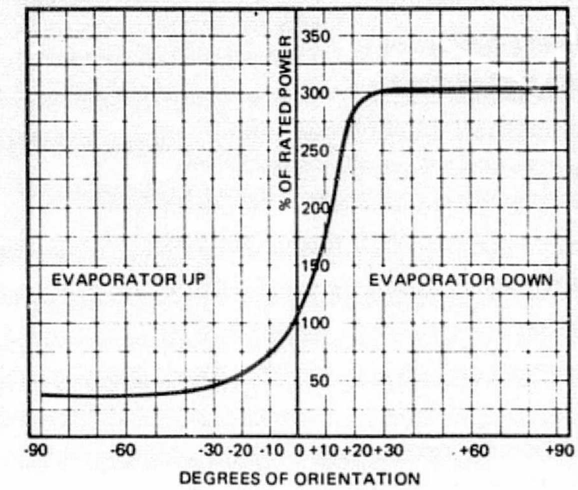
OUTLINE DRAWING



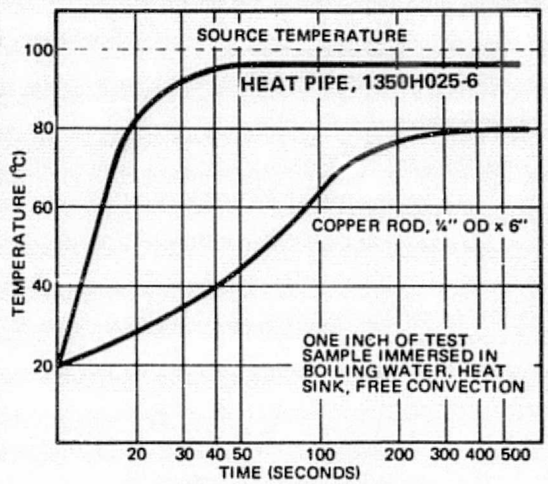
MODEL NO.	(A) Overall Length (in.)	(B) Active Length (in.)	(C) Pinch-Off Cover (in.)	(D) Diameter (in.)
1350H018-6	6.4	6.0	0.32	0.18
1350H025-6	6.4	6.0	0.32	0.25
1350H050-6	6.4	6.0	0.32	0.50

Figure 4
Heat Pipe Physical Characteristics and Performance Data

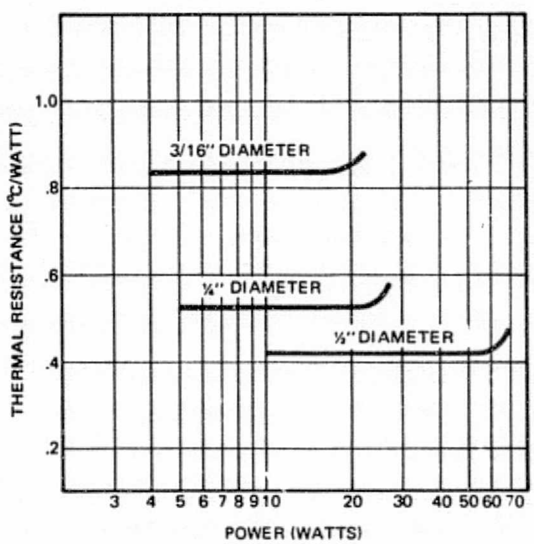
PERFORMANCE CURVES



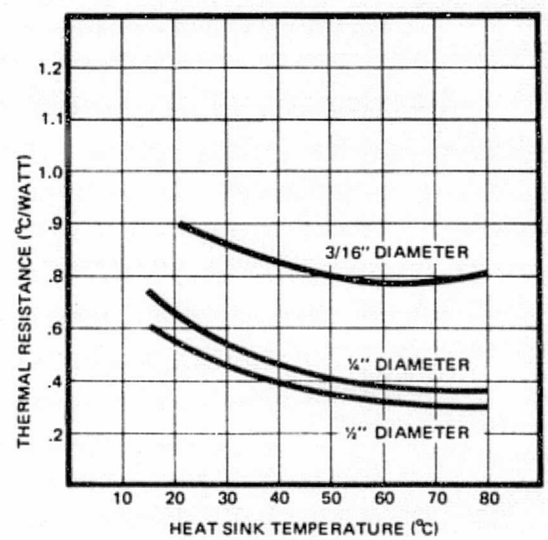
MAXIMUM POWER versus ORIENTATION



THERMAL RESPONSE TIME, HEAT PIPE versus COPPER ROD



THERMAL RESISTANCE versus POWER



THERMAL RESISTANCE versus HEAT SINK TEMPERATURE

Figure 4 (concl)

III. REVISED PACKAGING DESIGN

To evaluate the heat-pipe approach to thermal control of the output modules and its impact on size and weight, the prototype was reconfigured as shown in Figures 5, 6 and 7. Four plug-in output modules are supported by a base chassis containing the housekeeping circuits and power distribution wiring and connectors. Within the modules, the major dissipators were grouped together around a heat-pipe which conducts the heat to the base structure in the vicinity of the assembly mounting bolts. This provides a thermal shunt at the module/main-frame interface.

A. HEAT-PIPE INTEGRATION

The output regulator was redesigned to the configuration shown in Figure 7. The two PC board assemblies remained essentially unchanged because they followed good economical packaging practice and had relatively low power dissipation. The chassis-mounted components were repositioned in two columns flanking a 0.64-cm (0.25-in.) diameter heat pipe. This heat pipe extended from the top of the output regulator down through a hole in the chassis base and into a grooved boss in the main-frame support chassis adjacent to the mounting boss that is the primary thermal interface for the power supply.

To reduce the thermal gradient at the interface, a quick-release pivoted clamping device was provided in the main-frame support chassis to increase contact pressure between the heat pipe and main-frame chassis. The clamp is actuated by tightening a machine screw adjacent to the output regulator module mounting screw. To distribute forces more uniformly and preclude damage to the heat pipe, the heat-pipe clamp was faced with an elastomer.

In the output regulator module, the two power diodes and output transistors, which together dissipate close to 15 W, were placed on a grooved mounting bracket that serves as a saddle clamp for transferring thermal energy into the heat pipe. Clamping forces were provided by eight fasteners tying the semiconductors and mounting bracket securely to the module chassis. This ensured a high-pressure thermal interface joint with the heat pipe. The chassis and mounting bracket grooves were sized to ensure an interference fit for the heat pipe. Clamping forces caused elastic deformation of the bracket that allowed good thermal contact between the mounting bracket and chassis structure, thus providing redundant thermal paths for the major dissipators. Thermal analysis indicates that even with a failed heat pipe, the redundant

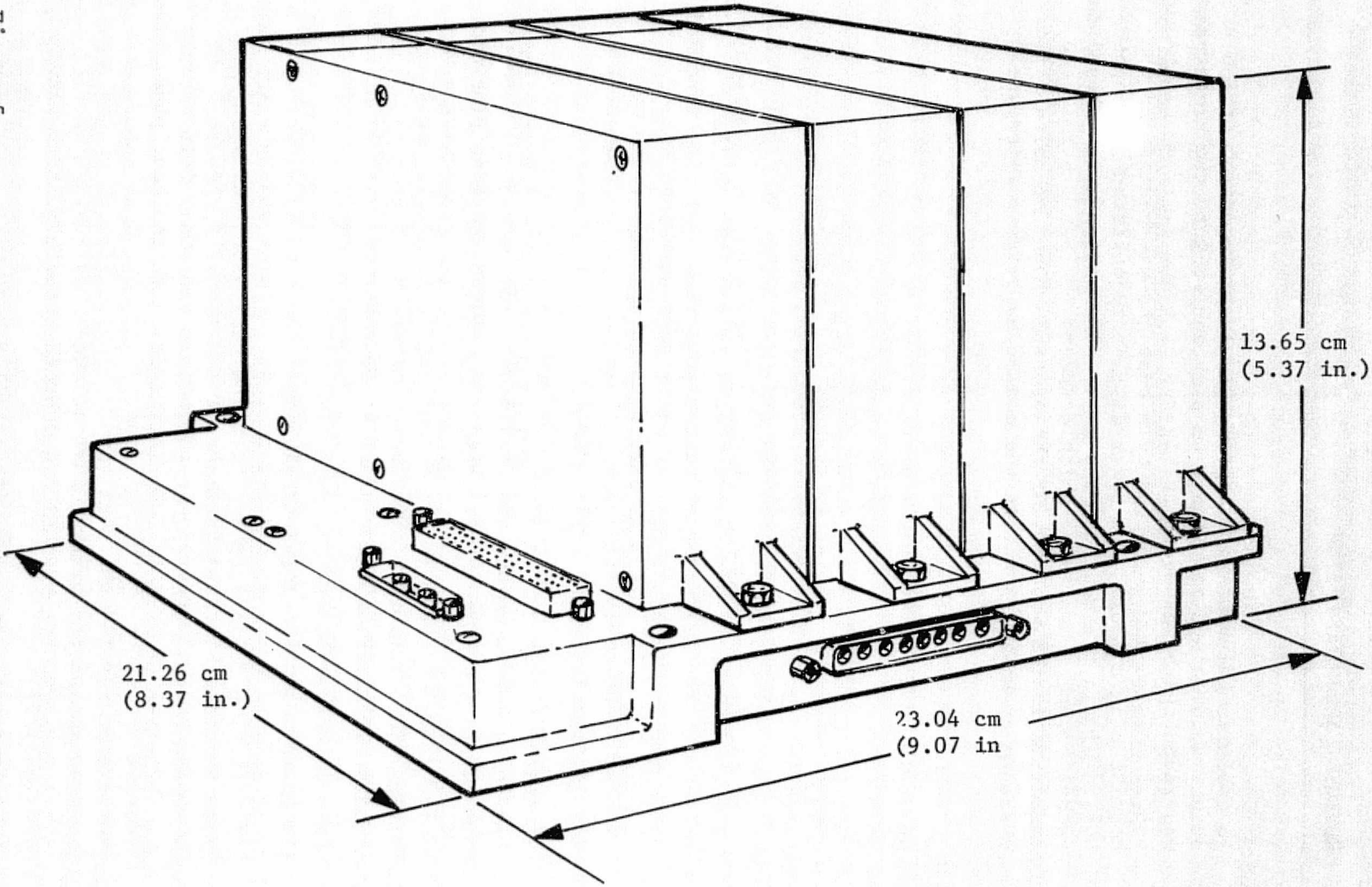
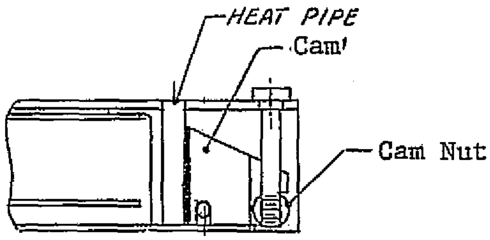


Figure 5 Modular Power Supply Assembly Outline



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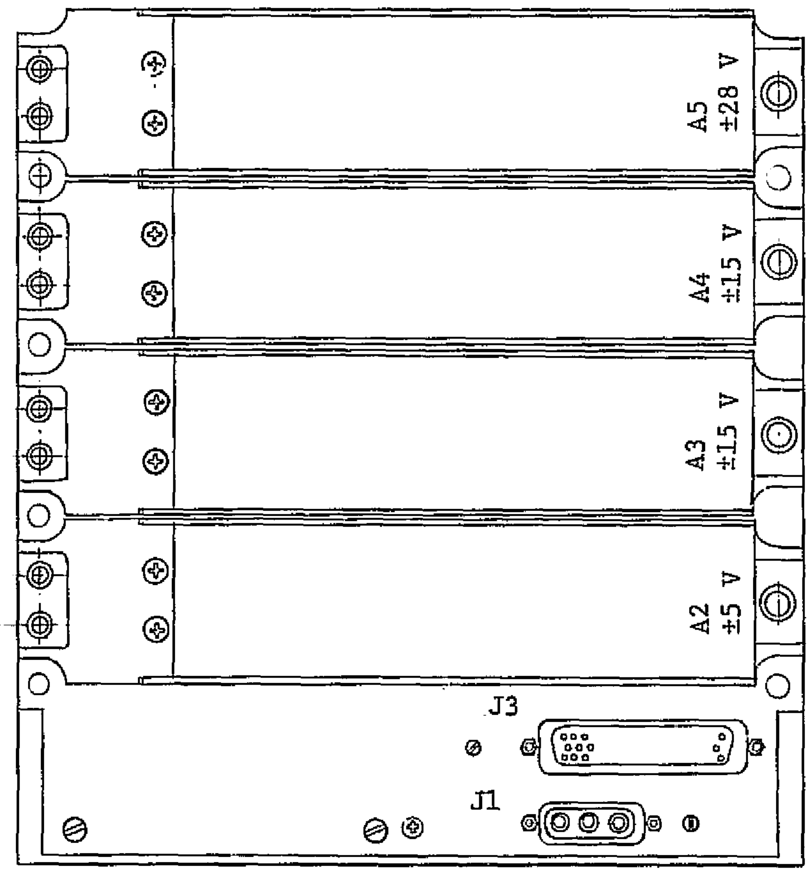
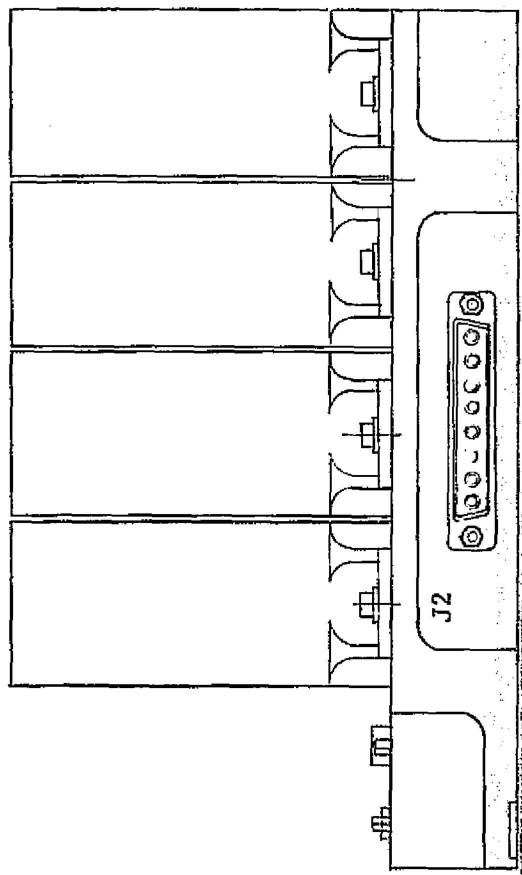




FOLDOUT FRAME

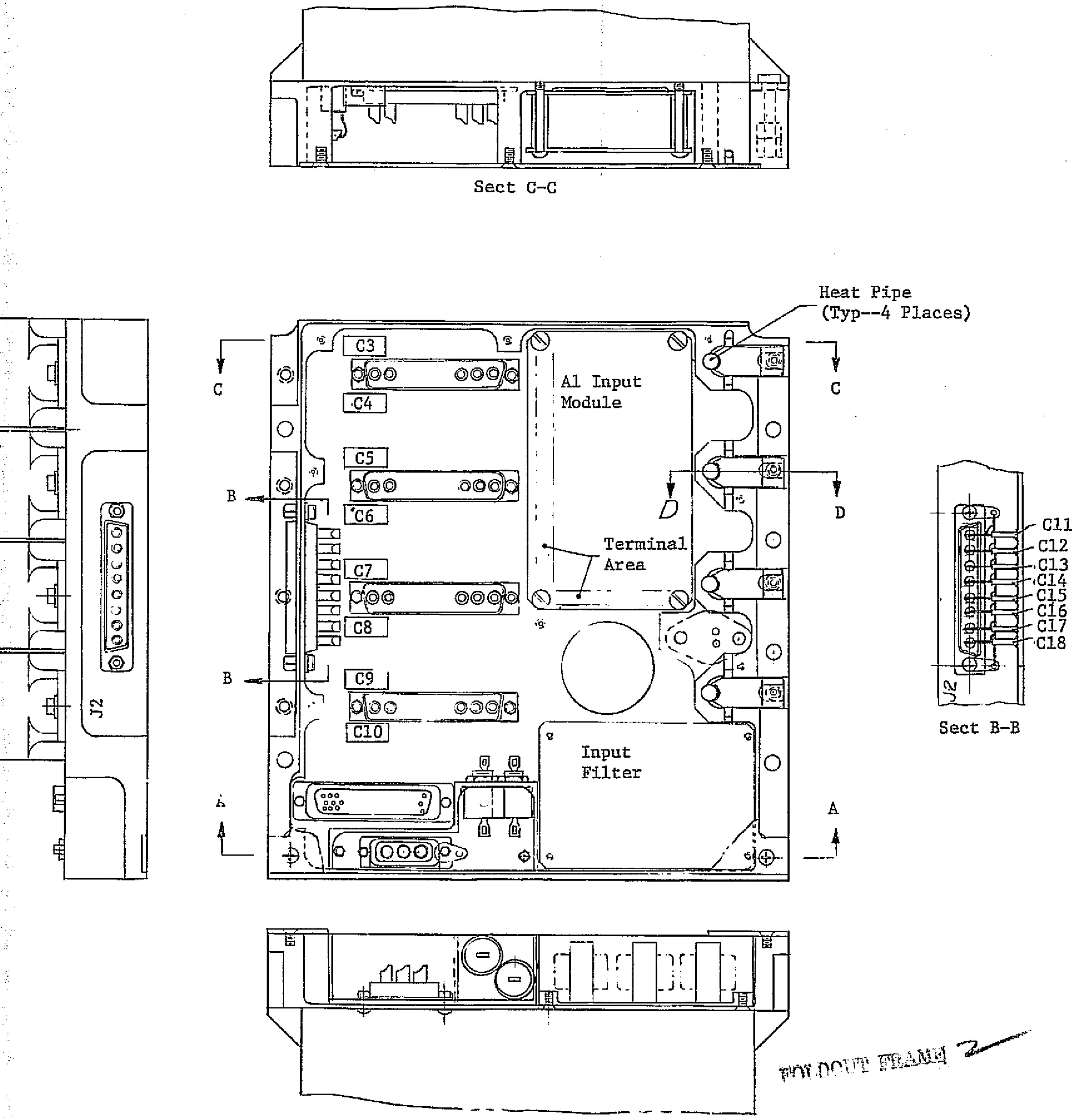


Figure 6 Multivoltage Modular Power-Supply Assembly Layout

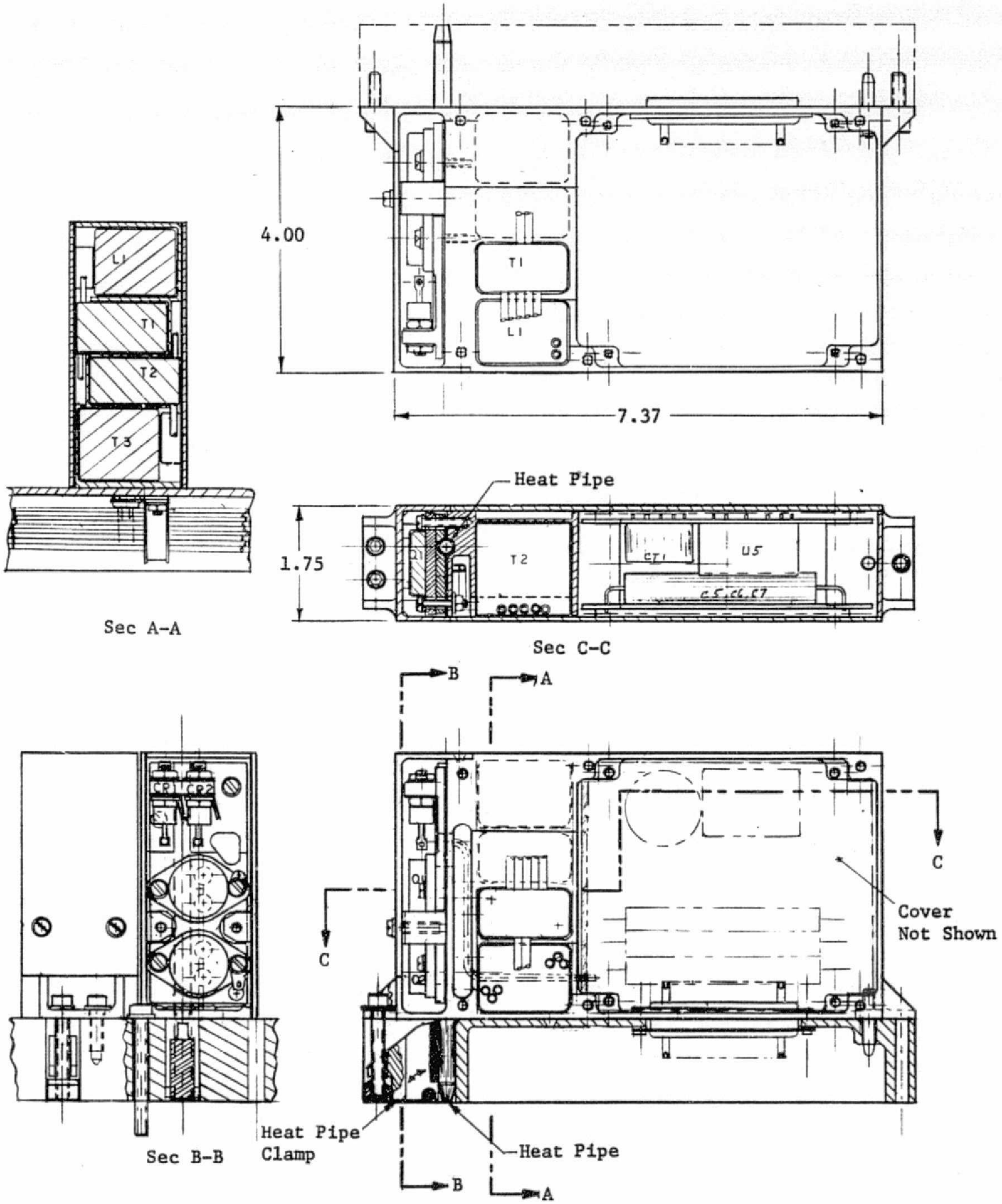


Figure 7 Output Regulator Module Layout

conduction paths were sufficient to maintain safe part temperatures. The degree of redundancy was reduced in the latest design configuration to maximize use of the heat pipe, reduce structural weight, and still provide adequate backup for the heat pipe in terms of thermal conduction paths.

Joint conductance was enhanced by using a thin film of thermal interface compound (Dow Corning DC-340) in areas of high thermal flux density such as heat pipe interfaces. This reduces thermal resistance to about one half that of a dry joint. With the heat pipe positioned between the chassis-mounted magnetics and the output semiconductors, temperature gradients were effectively reduced. The major effect of adding the heat pipe to this particular design was to reduce maximum part temperatures through more effective removal of generated heat. It provides more uniform temperature distribution in parts near the heat pipe.

B. OTHER THERMAL CONSIDERATIONS

The aluminum chassis and covers were given a black anodized finish to improve thermal radiation and provide a durable protective finish. The design requires a chemical film (iridite) treatment followed by black anodizing. After iriditing, mechanical interface areas (i.e., cover/chassis, faying surfaces) were masked off to preserve the electrically conductive finish for RFI control bonding. Due to the relatively poor thermal conduction paths to supporting structure, the use of black anodize to increase the emissivity for better radiant heat transfer is particularly helpful for PC board-mounted parts. The prototype thermal analysis predicted a decrease in average PC board temperature of about 8°C for the output regulator boards and 70°C for the input module boards by changing to a high-emissivity surface finish such as black anodize.

C. MAIN-FRAME REDESIGN

The main-frame chassis was redesigned to accommodate four plug-in output regulator modules mounted as shown in Figure 6. The housekeeping supply, failure monitoring circuitry, buffer circuits and filtering previously housed in a separate plug-in input module were repackaged and located within the main-frame assembly. The overvoltage and undervoltage buffer circuits were mounted on one printed circuit assembly with the relays positioned over heat sinks on the printed circuit board. The housekeeping regulator

inverter circuit board assembly was also revised to incorporate heat sinking for the more significant dissipators. Chassis-mounted parts and filtering elements were positioned to minimize cabling and to provide short thermal paths to the chassis mounting surfaces. Guided by the thermal analysis predictions, a modification was made to the input filter module which would reduce part temperatures within that module. An aluminum base plate was incorporated in the module to support the chokes and provide better themal interface for conduction to the main-frame chassis. Power distribution uses rectangular connectors with both 12 and 20-gage contacts to accommodate the current requirements. The centralized placement of the output connector simplifies internal wiring and allowed a more compact layout for the base chassis. Rear-mounted floating chassis connectors are used to interface with the plug-in modules. The design provides interchangeable mounting positions for the mechanically identical output modules.

In designing the main-frame structure, the load paths were maintained as short as possible. Intertial loads were carried directly from the module mounting fasteners into the main-frame side walls and to adjacent fasteners to secure the assembly to spacecraft structure. Six No. 10 fasteners were used for assembly mounting with four fasteners adjacent to the heat-pipe bosses along one side of the assembly. This promotes heat transfer accross the mounting interface. The opposite side adjacent to the module and output connectors requires only two assembly mounting fasteners due to a much lower thermal conduction load. Wall thicknesses were kept minimal to be consistent with structural and thermal conduction requirements, by machining external reliefs. This reduced weight without imposing undue complexity for fabrication. The main-frame bottom cover was recessed slightly and placed between rows of mounting bosses so that it did not add a thermal interface between the power supply and spacecraft structure.

Heat-pipe conducted thermal loads were applied directly to the main-frame structure at the ground interfaces adjacent to mounting bosses. Other thermal conduction paths from the plug-in modules coincide with the major structural load paths, thus assuring minimum thermal gradients due to the relatively heavy wall sections and clamped interfaces.

D. THERMAL ANALYSIS SUMMARY

A thermal model was developed for the reconfigured power supply. It was analyzed for normal operation and for a failed mode during which thermal dissipation was assumed to increase due to turn-on

of relays in the overvoltage/undervoltage buffer circuits. Environmental conditions were assumed to be those predicted for Space Tug equipment: i.e., isothermal panel mounting surface, +32.2°C, hot case: radiation environment, +22°C, hot case. Table 2 compares predicted temperatures for the baseline prototype design and the repackaged version for the 350-W total load condition. For this comparison, the +15V output regulator module A3 is summarized because it represents the worst-case output module from a temperature standpoint.

Based on the analysis predictions, the redesign power supply showed significant improvement in thermal performance. This reduced output module temperatures by more than 12°C in several areas. The predicted improvement in input electronics part temperatures is even more dramatic as shown by the comparison of module A1 temperatures for the baseline prototype design and the redesigned power supply. The overall reduction in temperature resulted from improved thermal conduction and radiation by relocating parts and by applying a thermal control finish to promote thermal radiation.

E. STRESS ANALYSIS SUMMARY

A preliminary stress analysis was performed on the redesigned assembly to assure structural adequacy of the design in a dynamic environment. An assumed load factor of 100g was used to be representative of dynamic loading conditions which might be encountered in its various applications. Factors of safety used in the analysis were 1.5 ultimate and 1.1 yield. Margins of safety were calculated for structural elements using a unit stress analysis and multiplying by the 100g load factor.

For this analysis, aluminum alloy 6061-T651 was used as the structural material employed. Alternate aluminum alloys considered suitable for use based on their stress allowables are: 7075-T73, 2024-T62, 2219-T6, and 2219-T861. If these alternate materials were selected, higher loads could be tolerated because their properties all exceed those of 6061-T651 alloy.

The analysis, presented in detail as Appendix B of this report, examined stresses in mounting hardware and primary load carrying members in the main-frame and output regulator chasses, determined allowable clamp loads for the heat-pipe, and calculated required bolt torques for mounting assemblies and heat-pipe clamping. The reconfigured power supply design was modified to reflect desired changes in wall thickness where the analysis showed either insufficient margins of safety or excessive stress capability.

Table 2 Temperature Predictions for Baseline Design and Redesign

	Ref Design	Dissipation, W	Predicted Temperatures, C° (F°)			
			Baseline Design		Redesign	
INPUT MODULE A1						
PC Board	A1	2.046	163	(325)	83	(181)
PC Board	A2	2.046	171	(340)	83	(181)
PC Board	A4	4.123	173	(343)	84	(183)
Filter	FL1	1.6	60	(140)	51	(124)
Filter	FL2	1.6	58	(136)	50	(122)
Transformer	T1	0.6	52	(126)	41	(106)
Transistor	Q1	7.9	58	(136)	52	(126)
Input Filter:	A5					
Choke	L3	1.2	107	(225)	85	(185)
Choke	L2	1.2	106	(223)	87	(189)
Choke	L1	1.2	99	(210)	82	(180)
Capacitors	C1→C4	0.8	102	(216)	84	(183)
OUTPUT REGULATOR A3						
PC Board (avg)	A1	2.173	80	(176)	62	(144)
PC Board (avg)	A2	0.956	72	(162)	58	(136)
Power Transistor	Q1	4.65	63	(145)	56	(133)
Power Transistor	Q2	4.65	59	(138)	56	(133)
Transformer	T1	0.15	56	(133)	49	(120)
Transformer	T2	0.15	54	(129)	49	(120)
Transformer	T3	1.80	59	(138)	50	(122)
Choke	L1	0.95	56	(133)	49	(120)
Power Diode	CR1	2.8	74	(165)	62	(144)
Power Diode	CR2	2.8	74	(165)	62	(144)

*Part case temperatures except for PC boards, which are average surface temperatures.

Typical margins of safety and factors of safety are listed in Table 3.

Table 3
Calculated Safety Factors and Margins of Safety for the SLCC Power Supply

Module mounting bolt, tension	MS = +0.31
Module end walls, tension	MS = +0.26
Module base, compression	MS = +1.65
Module gussets, tension	MS = +0.44
Module gussets, shear	MS = +0.50
Module web behind heat-pipe	FS = 1.22
Main-frame chassis bending	FS = 5.4

Modifications to the design since the analysis was performed include: (1) the addition of a center support for the main-frame bottom cover, and (2) reinforcement of the main-frame chassis top surface to provide added stiffness and better dynamic decoupling between these structural members and the main-frame circuit board assemblies.

IV. FABRICATION AND TEST RESULTS

A. FABRICATION AND ASSEMBLY

Machined details were fabricated from aluminum alloy 6061-T651 in the engineering model shop using conventional machining processes. In addition to the basic chasses, there were numerous covers, heat-pipe clamps, and mounting brackets to fabricate and process. The parts were iridited, masking was applied at the cover and connectors faying surfaces to assure electrical grounding at those interfaces, and a black anodize treatment was performed. During the chemical processing of the output module chasses, some accidental reduction in wall thickness occured. This resulted in these chasses being on the low side of their dimensional tolerances. However, their structural adequacy and thermal capability were not considered to have been jeopardized.

The printed circuit boards were supplier fabricated as were the magnetics used throughout the power supply assembly. Acceptance test criteria was provided for the magnetics supplier to assure proper performance of the transformers and chokes.

Electrical parts used in the assembly were military rated where schedule and cost permitted. Reduced reliability level parts (i.e., resistors and capacitors) were purchased to avoid excessive costs where minimum quantity procurement requirements would cause an unreasonable expenditure on this contract.

Assembly and check-out of the individual modules and main-frame were performed in the engineering laboratory facilities without difficulty. Output voltages for the 15-V housekeeping supply and output regulator modules were adjusted for nominal operation. The units performed within design tolerances over the full rated load range.

Subsequent to thermal vacuum testing, the circuit boards were conformal coated with a urethane material to provide added protection to the parts for future dynamic testing anticipated for the assembly at MSFC. Photographs of the hardware are shown in Figure 8 through 12. The photographs illustrate the easy accessibility afforded to most parts by the design with the covers removed to accommodate trouble shooting or repair.

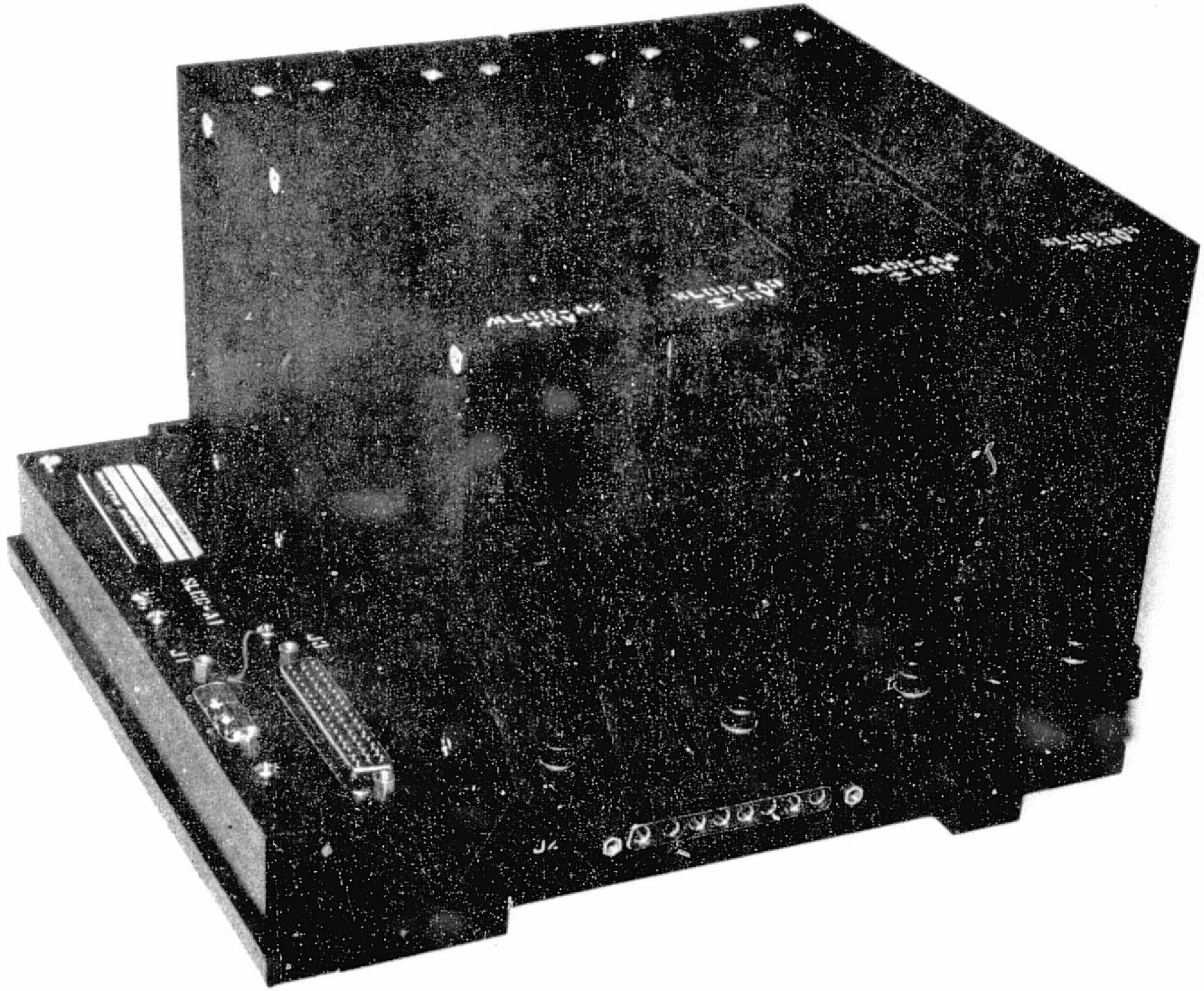


Figure 8 Revised Power-Supply Assembly

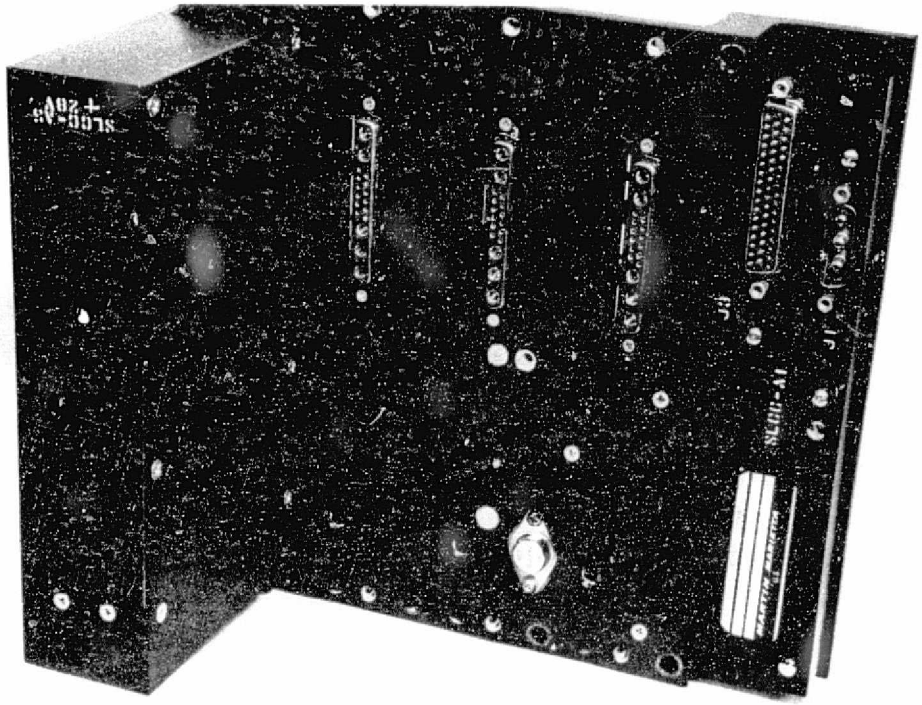


Figure 9 Main Frame Assembly with One Module

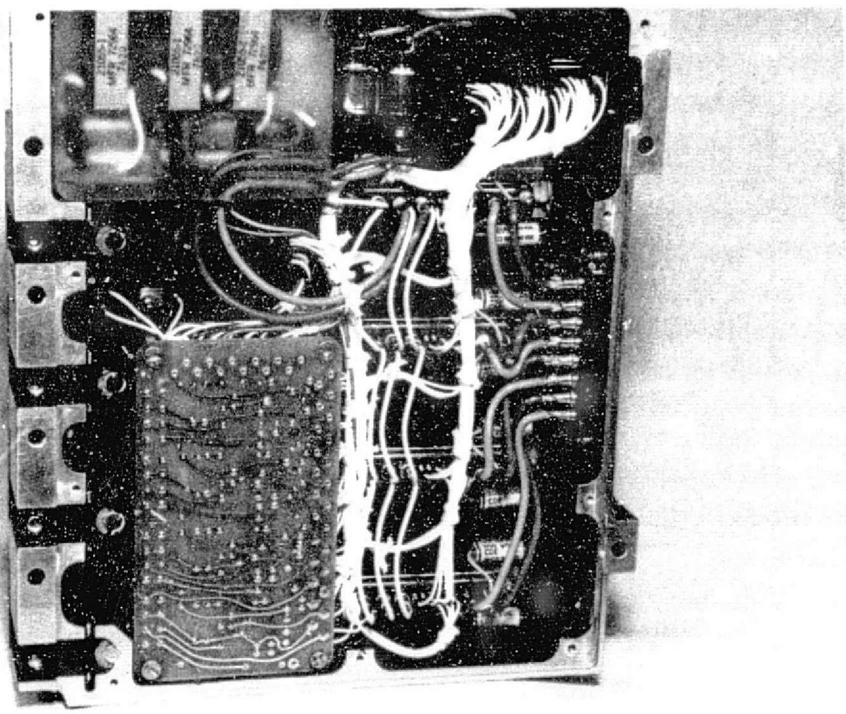


Figure 10 Main Frame Internal View

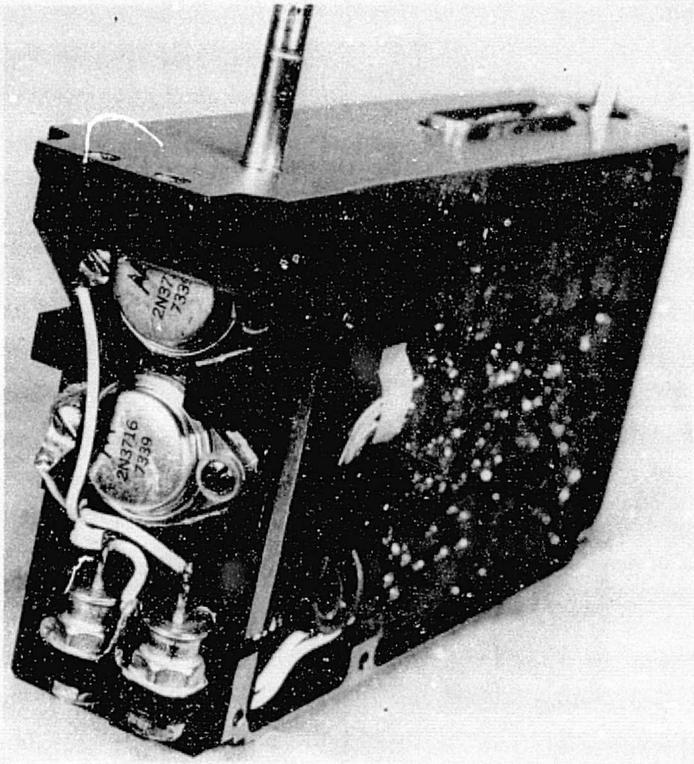


Figure 11 Semiconductor Mounting, Output Regulator

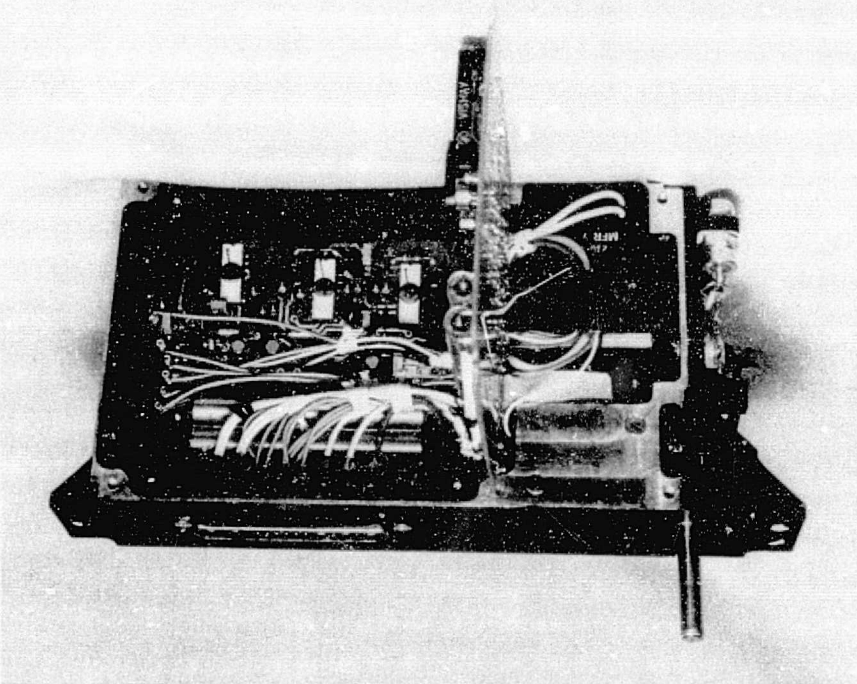


Figure 12 Circuit-Board Assemblies, Output Regulator

B. THERMAL VACUUM TESTING

After integrating the four plug-in output regulators with the main-frame assembly and assuring normal operation during bench tests, an environmental test was performed in the thermal-vacuum testing facility under conditions simulating the proposed Space Tug on-board equipment.

Thermocouples were installed on the unit at locations indicated in Figures 13 and 14. Four sensors were used for each output module and six were installed on the main frame assembly. In addition to the above, thermocouples monitored cold plate inlet and outlet temperatures and internal radiation shroud temperature.

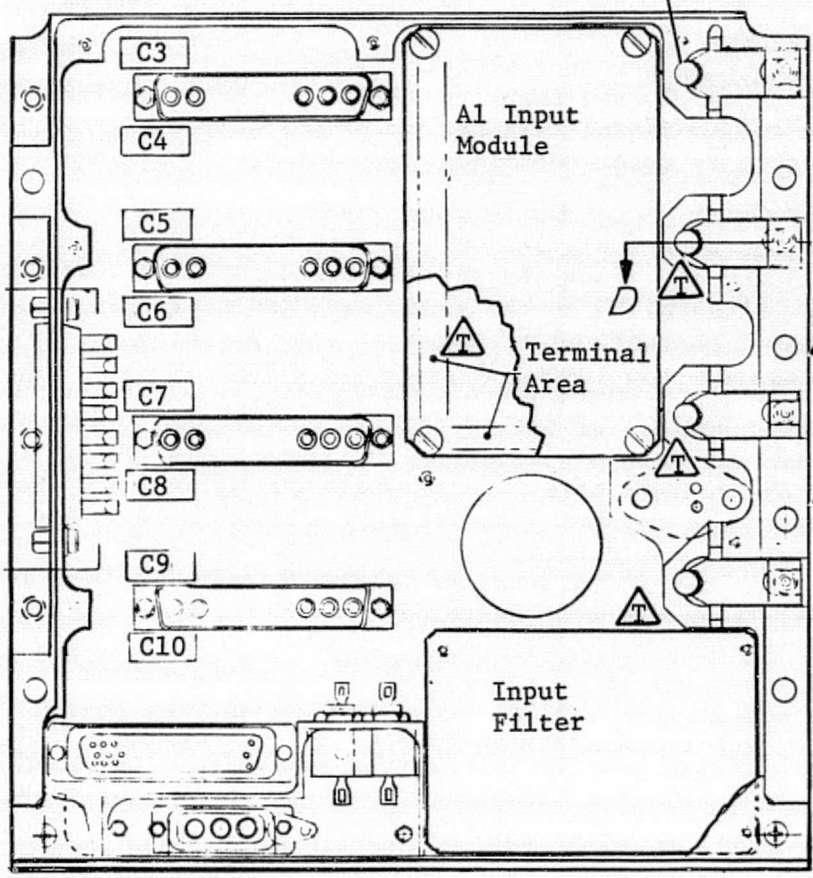
The mounting surface of the controlled cold-plate in the vacuum chamber was maintained at 32.2°C (90°F) and operating pressure was reduced to $<10^{-5}$ torr. To simulate the thermal radiation environment, the chamber internal shroud which surrounded the test article was held to 21°C (70°F). Approximately 1.5 hours of continuous operation at rated load were required to achieve essentially steady-state conditions.

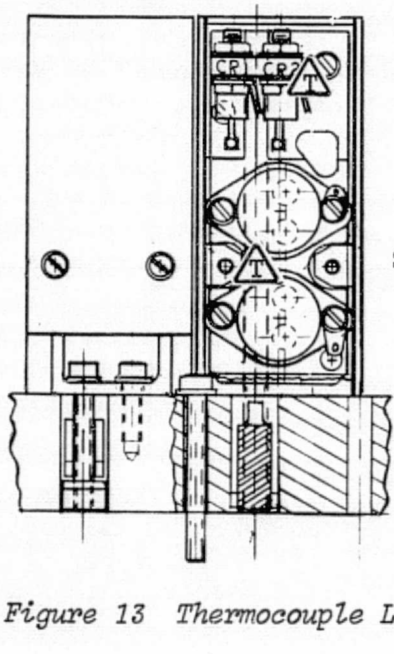
For this test, the power supply was operated in excess of rated load for six hours. Two runs of 2.5 hours each were made with the cold-plate temperature at 32.3°C (90°F). One additional test run was made with the cold-plate temperature increased to 49°C (120°F). Power measurements were made by measuring current and voltage at the power supply input bus and at each output load bank. Remote sense leads from each output regulator were attached at the load banks for proper output voltage regulation. The loads were adjusted for rated output power for each of the four output regulator modules. Table 4 lists power measurements taken at the external 28-V source and at the load banks. These readings remained essentially constant throughout the thermal-vacuum test.

Table 4 Thermal-Vacuum Test-Electrical Measurements

	Volts, dc	Amps	Watts
Power Supply Input	28.11	17.6	494.7
Output Regulator Module A2	4.99	9.8	48.9
Output Regulator Module A3	15.04	6.6	100.0
Output Regulator Module A4	15.01	6.6	99.1
Output Regulator Module A5	28.01	3.6	100.8

Correcting for distribution losses through the vacuum chamber penetration connectors and associated cabling (between the test article and the external instrumentation), the power supply input and output conditions experienced at its connector interfaces were calculated as follows:

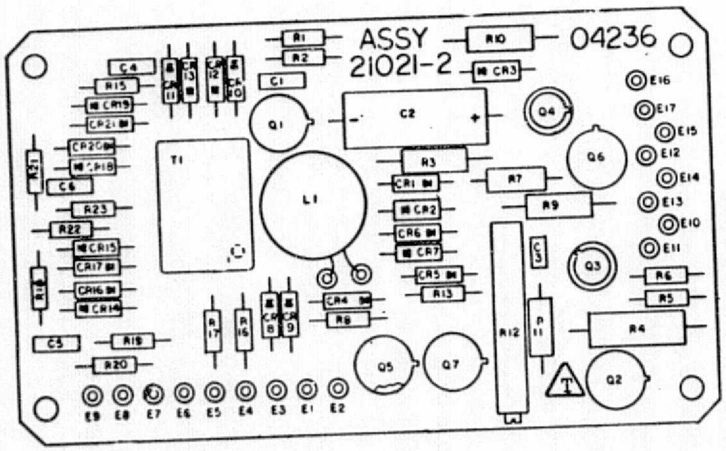




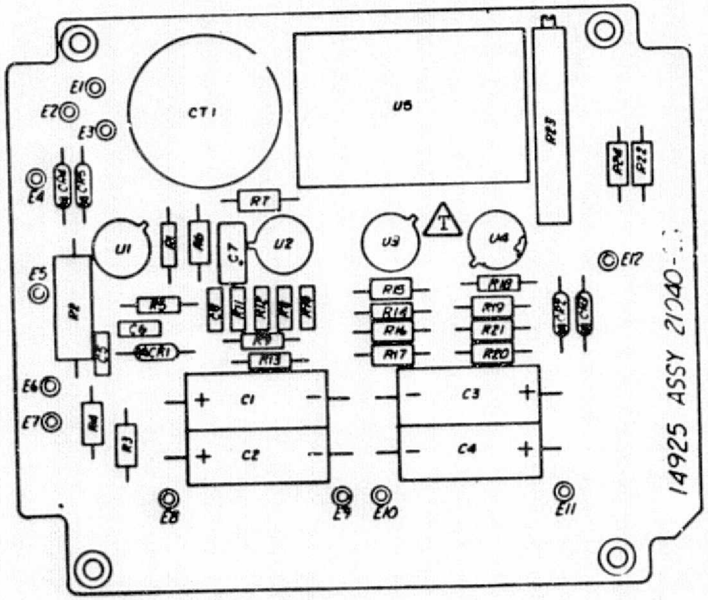
Sec B-B

Legend:
T Thermocouple Location

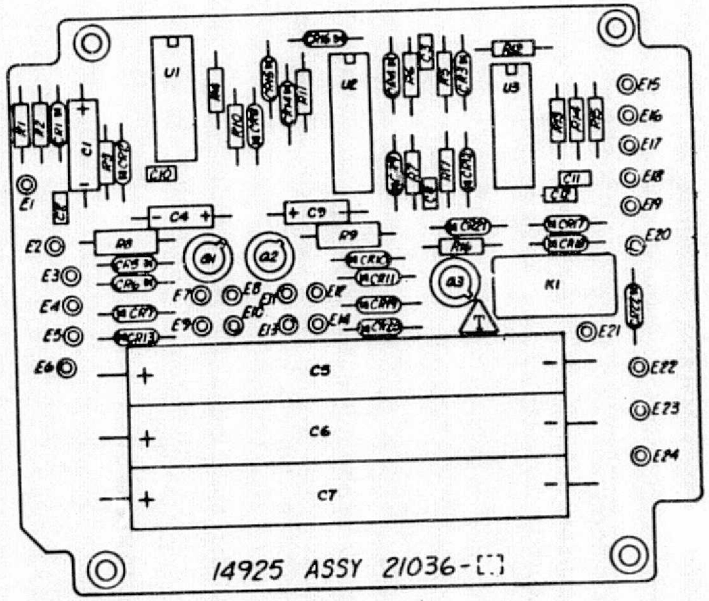
Figure 13 Thermocouple Locations, Chassis Mounted



a. Housekeeping Reg Inv



b. Error Amplifier



c. Control Logic

Figure 14 Thermocouple Circuit Board Assemblies

Table 5
Thermal-Vacuum Test-Adjusted Performance Values

	Volts, dc	Amps	Watts
Power Supply Input	26.6	17.6	468
Output Regulator Module A2	5.84	9.8	57.2
Output Regulator Module A3	15.61	6.6	103.8
Output Regulator Module A4	15.58	6.6	102.8
Output Regulator Module A5	28.32	3.6	101.9

Distribution losses amounting to 26.7 W of input power and 16.9 W of output power were calculated as I^2R power loss in the cables and penetration connectors between the unit under test and the instrumentation external to the chamber. Average resistance was determined to be 0.086 ohms per power distribution circuit.

In reviewing the test results, it was apparent that generally higher temperatures were experienced during the test than predicted by analysis. Table 6 compares measured results with analysis predictions.

The differences in measured versus predicted temperatures can be partially explained by the greater thermal dissipation under test; 102.3 W experienced versus the nominal 92.4 W dissipation used in the analysis. The increased thermal load resulted from driving the power supply at higher than rated output levels.

Some exceptions to the generally higher temperatures were noted in the input circuitry. The revised layout of the housekeeping supply circuit boards incorporating heat sinking for selected parts resulted in board surface temperatures of 51°C versus a predicted 65°C. In addition, the redesign of the input filter module incorporating a heat sinking base for thermal control of the input filter chokes and capacitors reduced temperatures from a predicted 85°C to less than 43°C.

Peak part temperatures in the output regulators were observed at the stud-mounted output diodes. Heat from the diodes is mostly conducted to the base-plate via the semiconductor mounting bracket and heat-pipe with redundant thermal paths existing at the mounting bracket/chassis interface. Conduction is strongly influenced by machining tolerances at these interfaces and the particular fit of the heat pipe in the machined grooves provided by the clamping arrangement. In comparing the test results for the two 15V output modules, A3 and A4, lower temperatures were noted for the output diodes and transistors of module A4, although by analysis they should be the same. Examination of the hardware showed a better fit between the mounting bracket, heat pipe, and chassis for module A4 as compared with A3. This could account for the difference in the temperatures observed. Module A3 represented a worst-cast tolerance build-up for purposes of heat transfer

by minimizing the redundant conduction paths at the mounting bracket/chassis interface. Since the heat pipe has sufficient capacity to handle the 15-W load without the redundant thermal paths, the temperature difference was limited to about 6°C with the highest part temperatures remaining below 72°C.

Table 6
Thermal Vacuum Test Results versus Predictions (32.2°C Cold Plate)

Locations	Observed Temperature, °C	Predicted Temperature, °C
Main Frame A1		
Mounting Surface	39	46
A3 Heat Pipe Clamp	42	41
A4 Heat Pipe Clamp	41	41
PC Board A3	51	78
Input Filter Base	41	39
5-volt Module, A2		
Output Transistors	63	48
Output Diode*		52
PC Board A1	57	59
PC Board A2	63	54
15-volt Module A3		
Output Transistors	64	56
Output Diodes	71	61
PC Board A1	61	62
PC Board A2	61	58
15-volt Module A4		
Output Transistors	56	56
Output Diodes	66	61
PC Board A1	69	62
PC Board A2	66	58
28-volt Module A5		
Output Transistors	67	55
Output Diodes	65	55
PC Board A1	63	62
PC Board A2	54	57

*Broken thermocouple.

C. SUPPLEMENTAL THERMAL VACUUM TEST

To evaluate the effect of an increased mounting plate temperature on the power supply, the cold-plate was controlled at 49°C, up from 32.2°C. Shroud temperature was maintained at 22°C and chamber pressure was 5.8 x $10.^{-6}$ torr. The electrical input and output power conditions were maintained at the same level described previously. The resulting steady-state temperatures are shown in Table 7.

Table 7
Supplemental Test Results with 49°C Cold Plate

Location	Observed Temperature °C
Main Frame A1	
Mounting Surface	53
A3 Heat Pipe Clamp	57
A4 Heat Pipe Clamp	57
PC Board A3	64
Input Filter Base	56
5-volt Module A2	
Output Transistors	74
Output Diode	-
PC Board A1	67
PC Board A2	74
15-volt Module A3	
Output Transistors	78
Output Diodes	83
PC Board A1	72
PC Board A2	73
15-volt Module A4	
Output Transistors	69
Output Diodes	78
PC Board A1	80
PC Board A2	78
28-volt Module A5	
Output Transistors	79
Output Diodes	78
PC Board A1	74
PC Board A2	63

Note that although the mounting plate temperature w[illegible]aised ~17°C, the average observed part temperature increase in the modules was only 11.7°C. This is partially the result of increased heat transfer by thermal radiation to the shroud due to higher power supply surface temperature relative to shroud temperature. In effect, the black anodized finish applied to promote radiant heat transfer reduced internal thermal conduction gradients by causing a greater portion of the dissipated power to be radiated to the shroud. In addition to the increased thermal radiation, the heat pipe thermal resistance is reduced with higher heat sink temperatures. This improves heat pipe performance by about 15%.

During the supplemental test, the maximum observed part temperature was ~34°C above the mounting plate temperature, reaching a high of 83°C at the output diodes of module A3. This would indicate that for reliable operation, the environmental maximum of 50°C mounting plate and 32°C ambient as a combined environment, are limits for this power supply configuration.

Reducing the cold-plate temperature would allow an increased ambient. The converse would also be true. To tolerate higher combined environments, additional mounting surface or improved thermal conduction would have to be incorporated as a design change.

D. WEIGHT AND VOLUME SAVINGS

The completed power supply, as tested, weighed 6.35 kg (14 lb). This represents a 44% reduction in weight from the prototype design estimated to weigh 25 lb for equivalent thermal performance. The effective use of heat-pipes to improve thermal conduction, and better utilization of the main-frame chassis were the two major factors instrumental in achieving the weight savings. Every effort was made to eliminate unnecessary structural material in the chassis design and to seek efficient thermal conduction paths and simplified wire routing. These all contributed to our exceeding the design goal in weight reduction. The power supply volume was reduced to 5166 cm^3 (315.2 $in.^3$) from the original 6738 cm^3 (411.1 $in.^3$) for a 23.3% reduction in size. Further minaturization would entail major changes in packaging techniques such as cordwood modules to achieve higher density which, although feasible, would adversely affect unit cost and seriously compromise maintainability. The present design employes low-cost two-sided printed circuit boards with full accessibility for fault isolation and repair at the part level which normally results in lowest production and maintenance costs for electronic equipment.

V. CONCLUSION AND RECOMMENDATIONS

This design study and development effort was undertaken to improve the packaging design of a prototype standard spacecraft power converter by reducing weight and size and assuring structural and thermal design adequacy for reliable space flight usage. The results have shown that, by careful integration of heat-pipes and economical use of structural material we can realize significant weight and volume savings and improve the overall thermal performance. Low-cost heat-pipes, available as off-the-shelf hardware, were employed to more efficiently manage the heat dissipated in the output regulators. This provides lower part temperatures with added advantages in reliability and expanded environmental capability.

The techniques described in this report were successfully employed in constructing and testing a modular 350 W power supply which was 44% lighter and 23% smaller than the first prototype design, based on equivalent thermal performance. The unit was designed to meet anticipated environments of Space Tug power conditioning equipment which was considered typical of the many applications in which this unit may be used.

There are no significant changes in the packaging design to recommend at this time. The thermal vacuum test results verified thermal design adequacy for the specified Space Tug environments. The structural design adequacy is to be verified in vibration testing at MSFC in the near future. Minor improvements in packaging design, such as increasing the module thickness by 0.25 cm (0.1 in.) to facilitate magnetics wiring should be incorporated when other changes are deemed necessary. Unit fabrication costs can be reduced by employing production fabrication techniques such as investment casting for chassis details. If the required quantities justify the tooling costs, the design can be easily adapted to alternate fabrication methods for significant overall cost savings.

APPENDIX A

THERMAL ANALYSIS FOR THE
MSFC POWER SUPPLY
SKL3179901

MARTIN MARIETTA CORPORATION

THERMAL ANALYSIS

FOR THE

MSFC POWER SUPPLY

SKL3179901

MARCH 29, 1976

PREPARED BY:

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W. T. Perreault
Product Development Technology
Electronics Department

FOREWORD

This report summarizes the technical analysis performed and includes sketches and tabulated data necessary to describe predicted operating temperatures of critical parts within the MSFC Power Supply, SKL3179901.

TABLE OF CONTENTS

1.0 SUMMARY

1.1 Purpose - This report documents the thermal analysis performed on the MSFC Power Supply Assembly, SKL3179901.

1.2 Scope - This report contains results of the analyses conducted to determine the thermal characteristics of the SKL3179901 Power Supply in Space Tug. This Power Supply is a re-packaging design of the O/R Modules, the Input Module, and the main frame chassis support structure for another MSFC Power Supply Assembly, 28956050. The redesign includes some structural optimization in the O/R Modules. The major innovation and improvement, however, was deleting the Input Module and placing its electronics (Input Electronics) in the main-frame chassis support structure.

1.3 Results - A summary of part temperatures for the Input Electronics and for the O/R Modules is contained in Appendix D. The environment in all cases is the application hot environment.

All temperatures are acceptable. Although the temperatures are good at the capacitors in the Input Electronics filter module, it would be an improvement to reduce them. This can easily be done by including some simple heat sinking in the module.

1.4 Power Dissipation - Total power dissipation in a non-failed mode is 92.385 watts. Total power for all O/R Modules failed was 95.973 watts. The difference results from turning on four relays in the Input Electronics that control power to failed O/R Modules.

No attempt was made to simulate any failed power condition within any of the O/R Modules. A breakdown of dissipations used in the thermal model is included in Appendix D. Listed below are the total dissipations for the individual modules.

Input Electronics		20.167 Watts Normal, 23.755 Watts Failed
O/R Module (+ 5V)	A2	13.121 Watts
O/R Module ($\pm$15V)	A3	20.499 Watts
O/R Module ($\pm$15V)	A4	20.499 Watts
O/R Module ($\pm$28V)	A5	18.099 Watts

1.5 Environment - The temperatures for the environment were taken from a study that was reported in Space Tug Thermal Control, document number MCR74147 (Contract NAS8-2960), September 1974. The system thermal control that was used in this study included isothermal panels with heat pipes and thermal control shutters. The power supply mounts on an isothermal panel.

Maximum temperatures occur while Tug is still inside Shuttle, preparing to be unloaded. Minimum temperatures occur about 30 hours later. The extreme temperatures are:

Isothermal Panel:	4.44°C to 32.2°C
Radiation Environment:	-173°C to 22°C

For the analyses, the radiation environment was changed to 26.7°C to make it compatible with a vacuum test chamber.

1.6 Thermal Model - In order to solve for internal temperatures within the several modules, a 404 node math model was generated to mathematically duplicate the physical relationships in terms of conductance, surface finish, view factor, and internal heat generated. See Appendix A for sketches of the Nodal Breakdown and see Appendix B for a description of the Conductors. Appendix C contains program control and power dissipation data.

The following information illustrates how the conductance parameters were programmed.

Solid Conduction

```
20,       8,9,       96. * 0.375 * 0.9/2.8/41.
Node      Node       KTW/L/C
No.       Linkages
                     Where: K = Thermal Conductivity (BTU-Ft/Ft^2-Hr-F°)
                            T = Thickness (in)
                            W = Width (in)
                            L = Path Length (in)
                            C = Conversion Factor (BTU-Ft/Hr to Watt-in)
```

Clamped Joint Conduction

```
149,166,    108,     0.624
                       G

                     Where:  G = Contact Conductance (Watts/°F)
```

Radiation

```
-151,    117,    161,  0.19 * 0.68 * 4.55 * 2.5/144./3.413
                        E * F * G W/C1/C2

                     Where: E = Emissity
                            F = View Factor
                            H = Height (in)
                            W = Width (in)
                            C1= Conversion factor (in^2 to ft^2)
                            C2= Conversion factor (BTU/Hr to Watts)

                     Note:  Sigma = Stephan-Boltzman radiation constant
                            (0.171 x 10^-8) is input as a constant
                                            elsewhere in the program.
```

1.7 Discussion of Results - The current power supply design incorporates heat pipes in all the O/R Modules. The heat pipes provide thermal shunts between the heat sinks for high power parts in the O/R Modules and the supporting chassis.

The main frame supporting chassis has been modified to house the input electronics that were previously in a separate module.

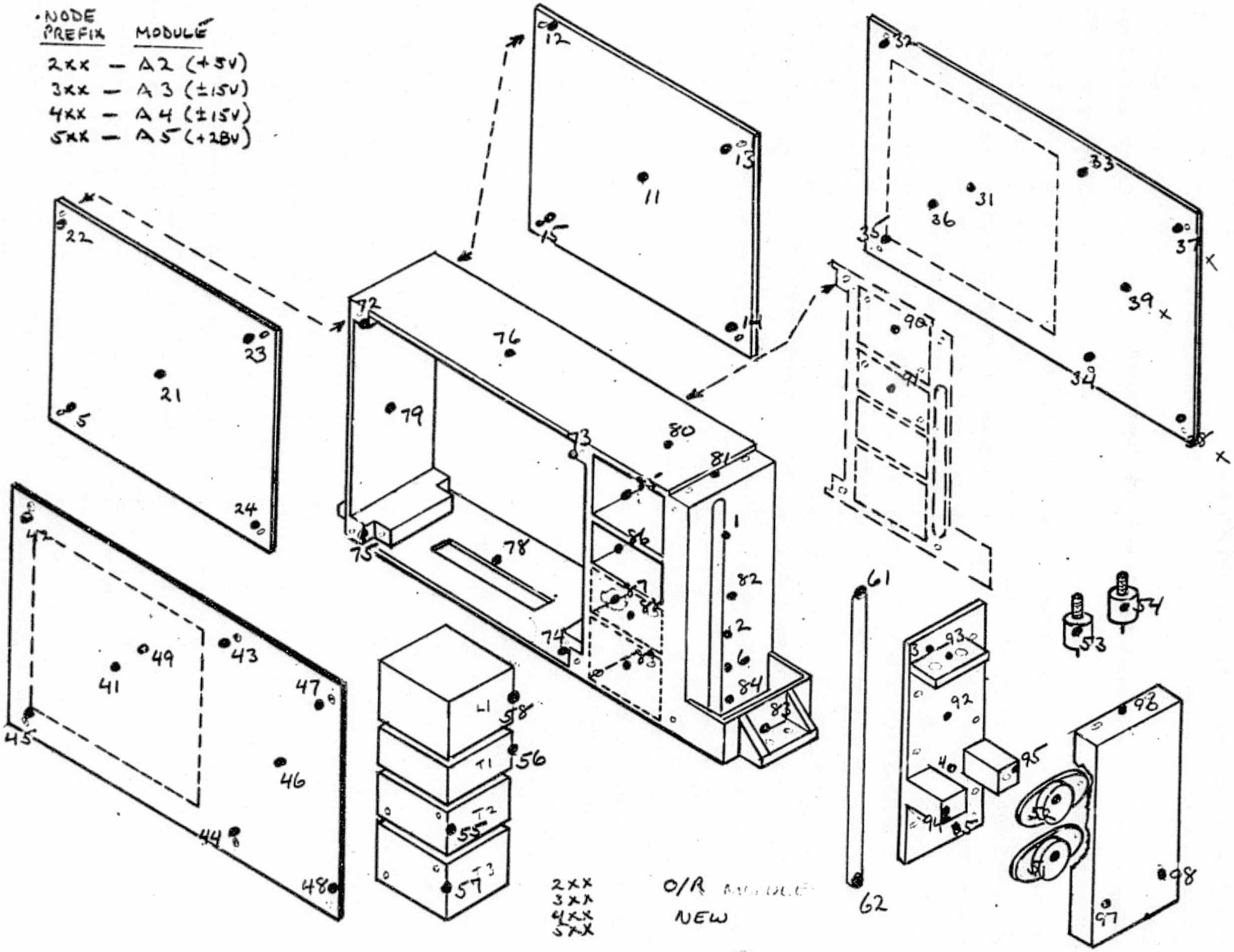
In the event that an O/R Module should fail, a relay in the Input Electronics is energized. As a worst case analysis, all four of these relays in the Input Electronics were turned on, with no adjustment of power dissipation in the O/R Modules.

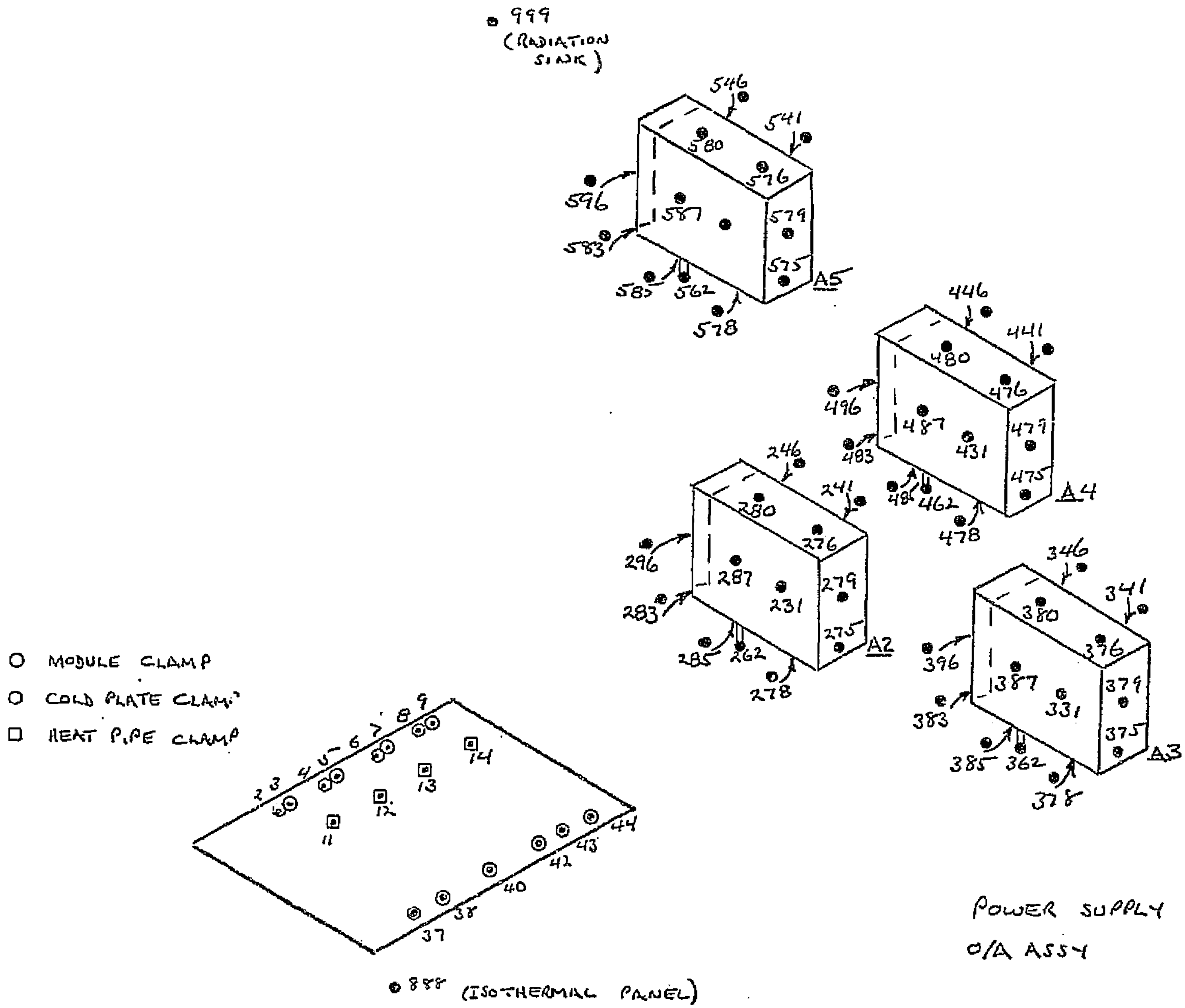
Analyses were run with the relays off and on. PC Board temperatures in the Input Electronics were somewhat high, so the conductances on the boards were changed, analytically, and the analyses re-run. The resulting temperatures are considered acceptable for reliable operation.

APPENDIX A

Thermal Model - Nodal Breakdown

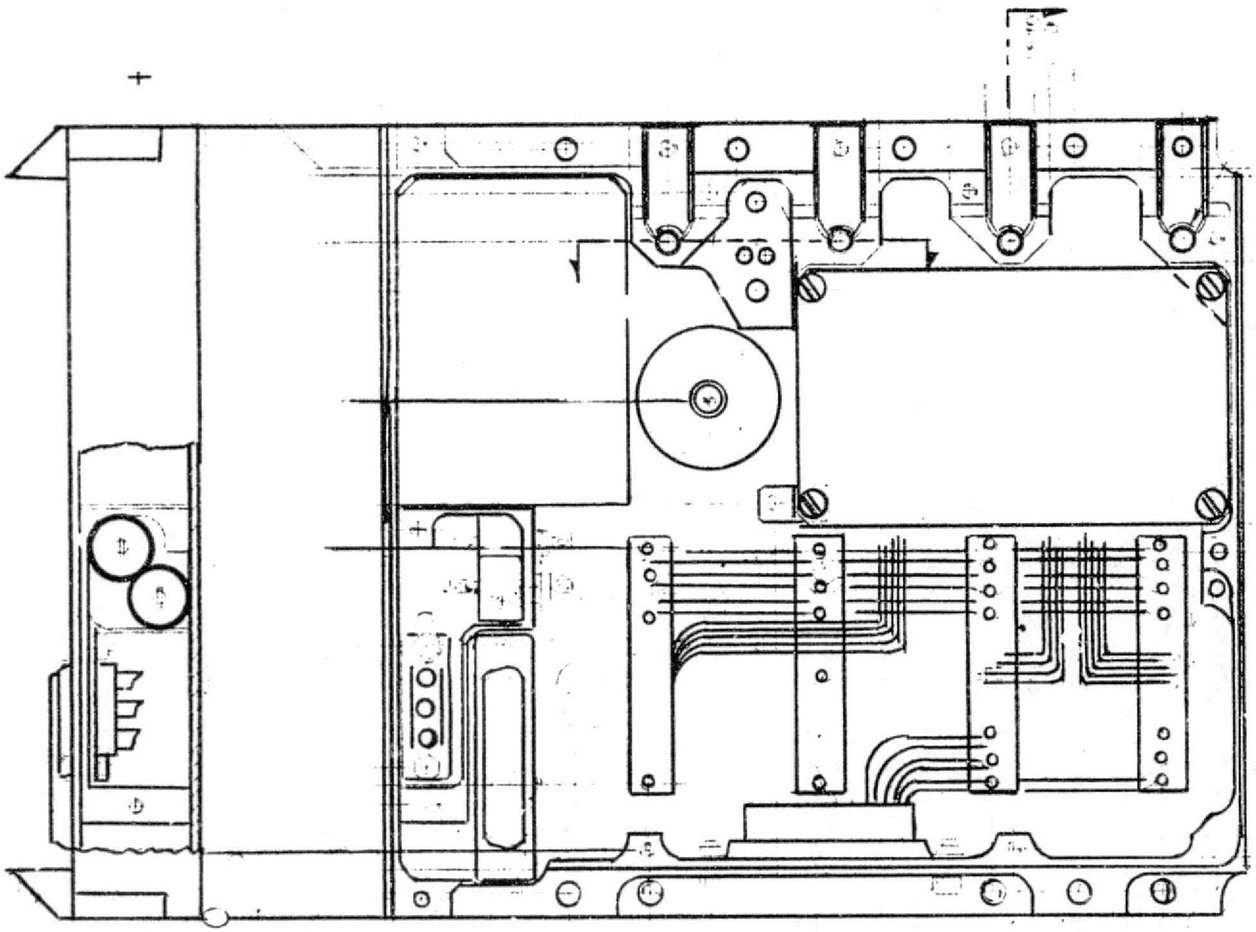
NODE PREFIX	MODULE
2xx	A2 (+5V)
3xx	A3 (±15V)
4xx	A4 (±15V)
5xx	A5 (+28V)



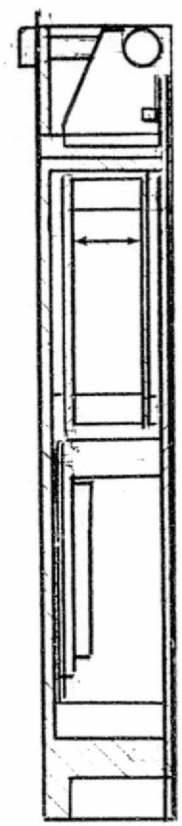


POWER SUPPLY
O/A ASSY

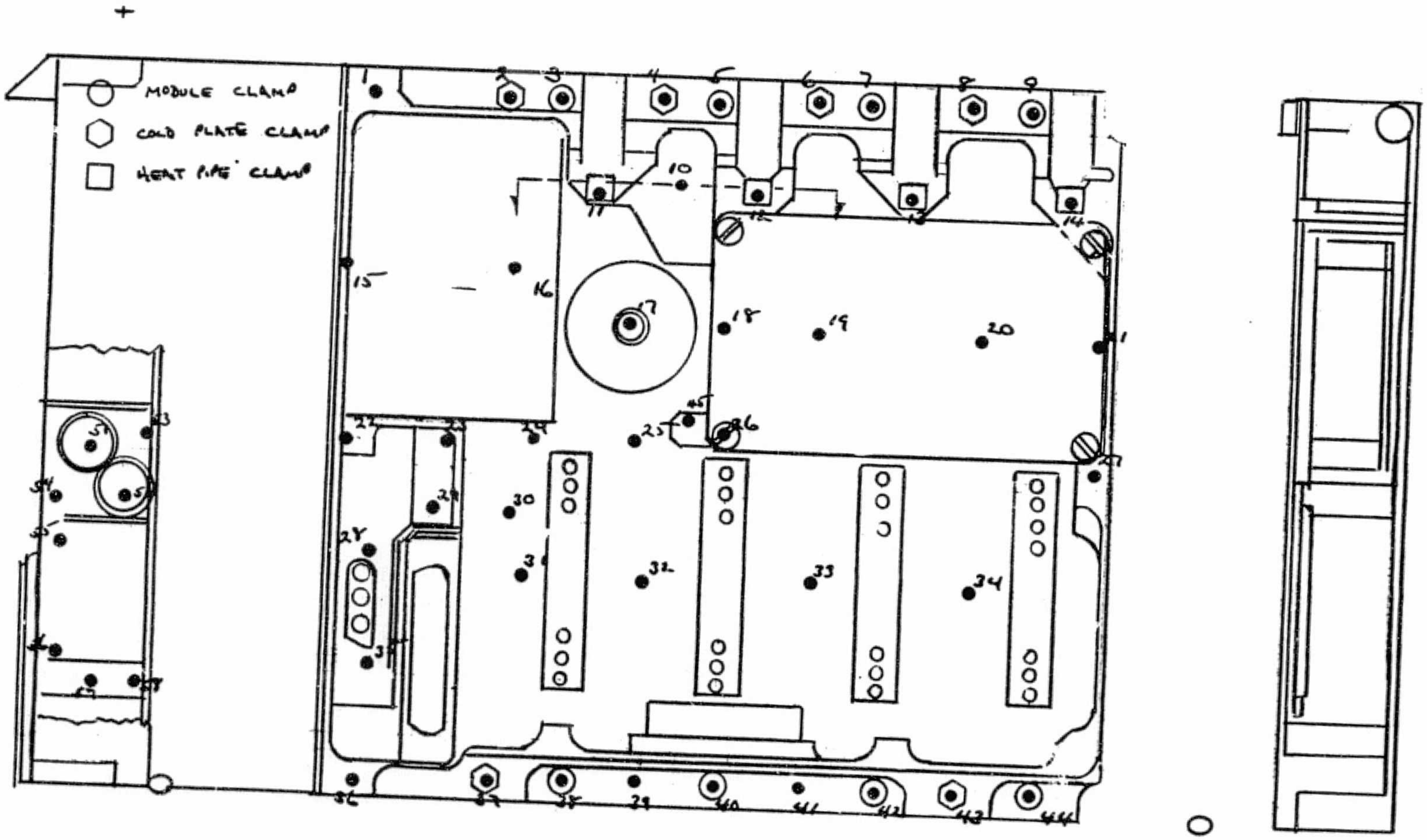
MAR. 1976



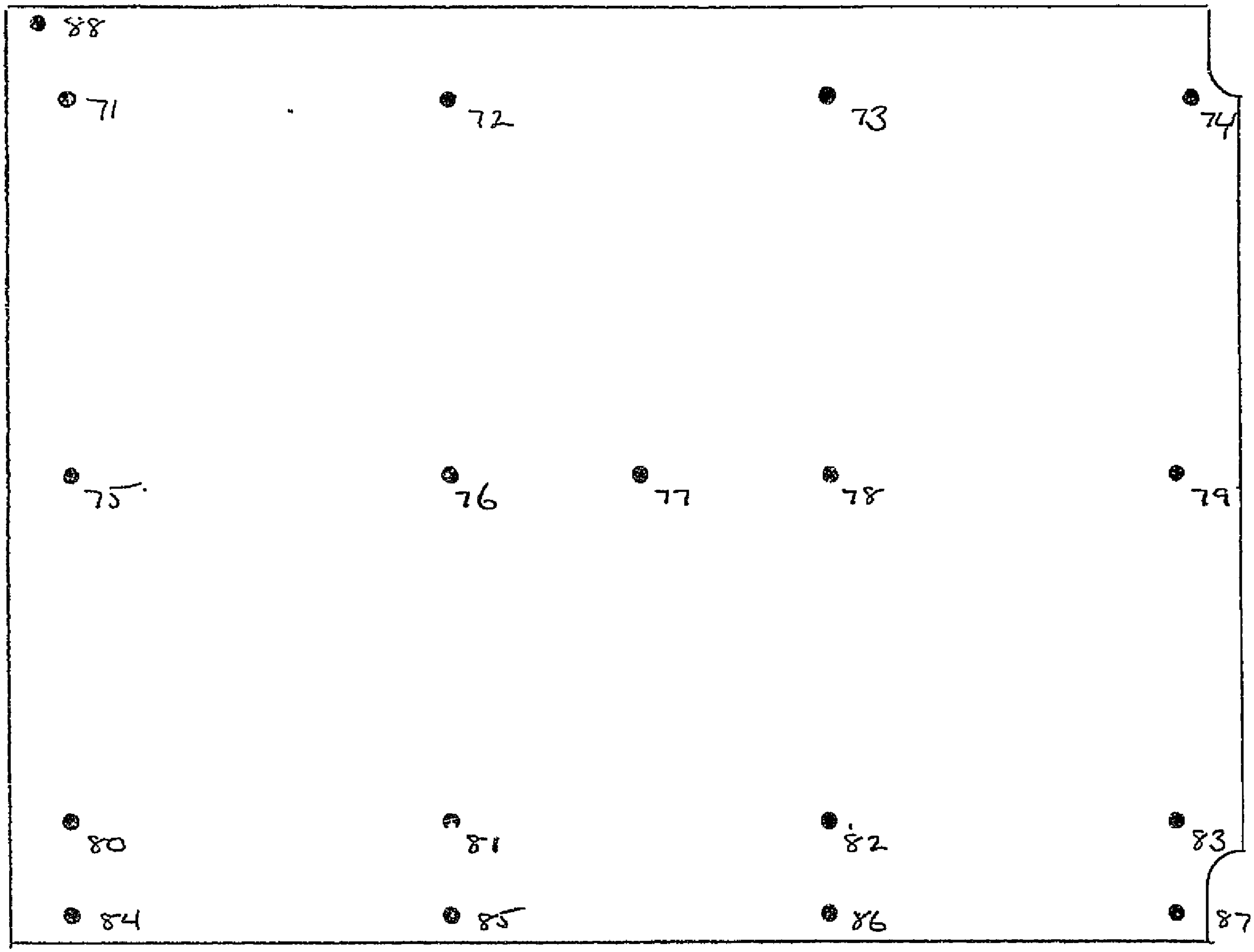
SUPPORT CHASSIS



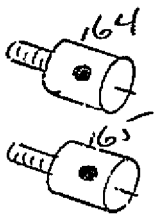
LOOKING DOWN THRU FROM ABOVE.

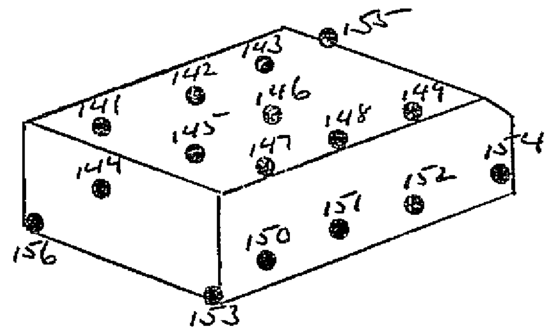


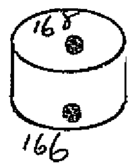
SUPPORT CHASSIS

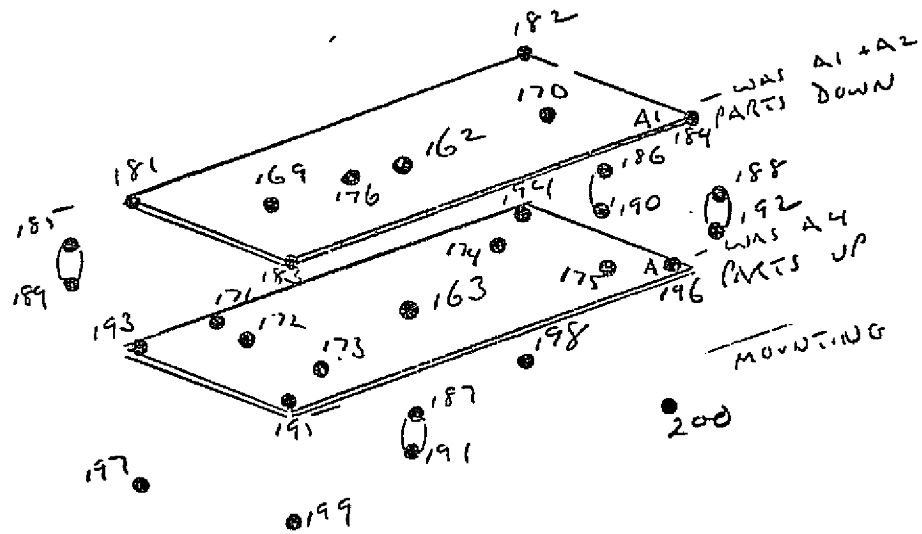


BOTTOM COVER
LOOKING FROM ABOVE









INPUT MODULE
PARTS

APPENDIX B

Conductors

```
      BCD 3CONDUCTOR DATA
C     BASEPLATE G
      1, 1,2,                  96.*.800*.40/1.2/41.
      2, 36,37,                96.*.650*.40/1.2/41.
      GEN 3,4,0,2,2,3,2,       96.*1.40*.50/.60/41.
      GEN 4,3,0,3,2,4,2,       96.*1.00*.07/.60/41.
      GEN 5,2,0,3,6,11,3,      96.*1.18*.21/.80/41.
      GEN  6,2,0,5,2,12,1.     96.*1.18*.25/.90/41.
      7, 5,12,                 95.*1.18*.25/.80/41.
      8, 4,11, 7,13,           96.*1.18*.37/1.5/41.
      9, 11,10, 10,12,         96.*1.00*.18/.60/41.
      10, 12,13, 13,14.        96.*.700*.07/.80/41.
      11, 15,16, 19,20.        96.*2.90*.07/1.9/41.
      12, 16,17.               96.*2.60*.07/1.4/41.
      13, 17,18,18,19,26,19,95.*1.40*.07/1.1/41.
      14, 20,21,               96.*1.70*.07/1.4/41.
      GEN 15,4,0,22,1,23,1, 96.*1.10*.07/1.1/41.
      16, 23,29, 24,30,        96.*1.10*.07/1.1/41.
      17, 28,29,29,30,30,31,96.*1.10*.07/1.1/41.
      GEN 18,4,0,38,1,39,1. 96.*.938*1.0/0.8/41.
      19, 37,38,42,43,43,44,96.*1.00*.33/0.5/41.
      20, 1,15, 15,22,         96.*1.40*.14/2.0/41.
      21, 1,15, 15,22.         96.*1.30*.07/2.0/41.
      22, 2,16, 16,24,         96.*1.30*.07/2.0/41.
      23, 11,17,17,25,18,26,96.*1.00*.07/1.4/41.
      24, 10,18,               96.*1.00*.07/1.0/41.
      25, 12,19,               96.*1.30*.07/1.4/41.
      26, 13,20,               96.*1.90*.07/1.4/41.
      27, 14,21, 21,27.        96.*1.35*.20/1.5/41.
      28, 19,33, 20,34,        96.*1.50*.07/2.9/41.
      29, 22,29, 35,36.        96.*1.70*.14/1.3/41.
      30. 28,35,               96.*1.60*.14/1.2/41.
      31, 31,37,               96.*1.95*.07/2.1/41.
      32, 25,32,               96.*1.30*.07/1.6/41.
      33, 32,39,33,41,34,43,96.*1.30*.07/2.0/41.
      34, 27,44,               96.*1.70*.14/3.2/41.
      35. 26,45,               96.*.360*.40/1.1/41.
      41, 51,52,               96.*.700*.10/.70/41.
      42, 51,53,               96.*1.10*.07/1.1/41.
      43, 52,54,               96.*1.00*.07/.80/41.
      44, 54,55,               96.*0.60*.08/.90/41.
      45, 53,55,               96.*1.30*.08/2.3/41.
      46, 52,57,               96.*1.30*.08/2.7/41.
      47, 56,57, 57,58,        96.*.700*.35/.60/41.
      48, 54,29, 55,28, 56,35, 57,35, 0.625
C     BOTTOM COVER
      51, 88,71,               96.*1.70*.06/.90/41.
      52, 71,72,72,73,73,74,96.*2.50*.06/2.6/41.
      53, 75,76, 78,79.        96.*3.50*.06/2.6/41.
      54, 76,77, 77,78,        96.*3.50*.06/1.3/41.
      55, 80,81,81,82,82,83,96.*2.50*.06/2.6/41.
      56, 71,75, 74,79,        96.*1.50*.06/3.0/41.
      57, 72,76, 73,78,        96.*3.00*.06/3.0/41.
      58, 75,80, 79,83,        96.*1.50*.06/2.7/41.
      59, 76,81, 78,82,        96.*3.00*.06/2.7/41.
      60, 80,84, 83,87,        95.*1.50*.06/1.1/41.
      61, 81,85, 82,86.        96.*3.00*.06/1.1/41.
//
```

```
C       ATTACH COVER TO CHASSIS
C       NOT ILLUSTRATED
        62, 88,1, 72,4, 73,7, 74,14, 77,45
            79,27, 84,36, 85,38, 86,42, 87,44, 0.625
C       ATTACH FILTER FRAME TO COVER
        63, 53,75, 58,80,   0.625
C       ASSUMED CONDUCTANCES ON INPUT MODULE PC BOARDS
C       WATCH THESE DURING PC BOARD LAYOUT *    *     *     *     *     *     *     *
        101, 181,169, 183,169, 182,170, 184,170
                     200.*.0027*0.7/0.6/41.
        102, 171,193, 172,193,173,195, 174,194, 175,196
                     200.*.0027*0.4/0.4/41.
C       BOARD STANDOFFS - 6061-T6 ALUMINUM %.3 OD, .15 ID<
        GEN 103, 4,0,185,1,189,1, 96.*.053/.8/41.
C       USE 7 PLATED THRU HOLES OF .03 DIAMETER AT EACH CORNER
C       FOR THROUGH THE BOARD CONDUCTANCE
        GEN 104,4,0,193,1,197,1, 7./100.
        GEN 105,4,0,181,1,185,1, 0.625
        GEN 106,4,0,189,1,193,1, 0.625
        107, 197,26, 199,12, 198,27, 200,14, 0.625
        GEN 108,4,0,162,0,181,1,    200.*.0027*.03*.04/2.0/41.
        GEN 109,4,0,163,0,197,1,    200.*.0027*.03*.04/2.0/41.
        110, 176,162, 1.0
        133, 155,143,   .8*.50*0.75/0.4/41.
        134, 153,150,   .8*.40*0.30/0.2/41.
        135, 154,152,   .8*.40*0.30/0.2/41.
        136, 141,142,   .8*.80*0.6/.12/41.
        137, 142,143,   .8*.80*0.6/.12/41.
        138, 141,142,   .8*.72     /.60/41.
        139, 142,143,   .8*.72     /.60/41.
        GEN 140,3,0,141,1,144,1, .8,.9,1.3,.25*41.
        GEN 141,3,0,141,1,147,1, .8,.8,0.4,0.1*41.
        GEN 142,3,0,141,1,147,1, .8,.5,0.8,0.3*41.
        GEN 143,3,0,147,1,150,1, 200.,4.*1.,.005,1.1*41.
        144,147,148, 148,149, 150,151, 151,152, 200.*.0019/1./2./41.
C       ADD FOURTH SCREW ATTACHMENT FOR INPUT FILTER MODULE
        145, 144,156, .8*.4*.3/.2/41.
        147, 164, 51, 165, 52, .15
        148, 167, 10, .53
        149, 166, 17, .625
        150, 153, 22, 154,  1, 155,  3, 156,24, 0.625
        164, 166,168,             .8*1.5*.7/.7/41.
        201, 241,249, 231,236, 341,349, 331,336, 441,449, 531,536
            541,549, 431,436,           2.0
        GEN 202,4,0,231,0,232,1,96.,.06,3.0,2.7*41.
        GEN 302,4,0,331,0,332,1,96.,.06,3.0,2.7*41.
        GEN 402,4,0,431,0,432,1,96.,.06,3.0,2.7*41.
        GEN 502,4,0,531,0,532,1,96.,.06,3.0,2.7*41.
        GEN 203,4,0,241,0,242,1,96.,.06,3.0,2.7*41.
        GEN 303,4,0,341,0,342,1,96.,.06,3.0,2.7*41.
        GEN 403,4,0,441,0,442,1,96.,.06,3.0,2.7*41.
        GEN 503,4,0,541,0,542,1,96.,.06,3.0,2.7*41.
        GEN 204,2,0,246,0,243,1,96.,.06,1.0,2.0*41.
        GEN 205,2,0,246,0,247,1,96.,.06,1.0,2.0*41.
        GEN 304,2,0,346,0,343,1,96.,.06,1.0,2.0*41.
//
```

```
GEN 305,2,0,346,0,347,1,96.,.06,1.0,2.0*41.
GEN 404,2,0,446,0,443,1,96.,.06,1.0,2.0*41.
GEN 405,2,0,446,0,447,1,96.,.06,1.0,2.0*41.
GEN 504,2,0,546,0,543,1,96.,.06,1.0,2.0*41.
GEN 505,2,0,546,0,547,1,96.,.06,1.0,2.0*41.
GEN 206,4,0,241,100,246,100,96.,.06,4.0,3.2*41.
GEN 207,4,0,231,100,239,100,96.,.06,4.0,3.2*41.
GEN 208,2,0,239,000,233,001,96.,.06,1.0,2.0*41.
GEN 308,2,0,339,000,333,001,96.,.06,1.0,2.0*41.
GEN 408,2,0,439,000,433,001,96.,.06,1.0,2.0*41.
GEN 508,2,0,539,000,533,001,96.,.06,1.0,2.0*41.
GEN 209,2,0,239,000,237,001,96.,.06,1.0,2.0*41.
GEN 309,2,0,339,000,337,001,96.,.06,1.0,2.0*41.
GEN 409,2,1,439,000,437,001,96.,.06,1.0,2.0*41.
GEN 509,2,0,539,000,537,001,96.,.06,1.0,2.0*41.
GEN 210,4,0,211,0,212,1,200.,.0027,.02,2.5*41.
GEN 310,4,0,311,0,312,1,200.,.0027,.02,2.5*41.
GEN 410,4,0,411,0,412,1,200.,.0027,.02,2.5*41.
GEN 510,4,0,511,0,512,1,200.,.0027,.02,2.5*41.
GEN 211,4,0,221,0,222,1,200.,.0027,.02,2.5*41.
GEN 311,4,0,321,0,322,1,200.,.0027,.02,2.5*41.
GEN 411,4,0,421,0,422,1,200.,.0027,.02,2.5*41.
GEN 511,4,0,521,0,522,1,200.,.0027,.02,2.5*41.
GEN 212,4,0,275,100,278,100,96.,.06,1.00,1.7*41.
GEN 213,4,0,278,100,274,100,96.,.06,1.00,1.7*41.
GEN 214,4,0,272,100,276,100,96.,.06,1.66,1.7*41.
GEN 215,4,0,276,100,273,100,96.,.05,1.66,1.7*41.
GEN 216,4,0,275,100,279,100,96.,.06,1.66,1.7*41.
GEN 217,4,0,279,100,272,100,96.,.06,1.66,1.7*41.
GEN 218,4,0,273,100,280,100,96.,.06,1.66,0.8*41.
GEN 219,4,0,280,100,281,100,96.,.05,1.66,0.8*41.
GEN 220,4,0,281,100,201,100,96.,.45,1.60,0.4*41.
GEN 221,4,0,282,100,202,100,96.,.282,1.0,0.9*41.
GEN 222,4,0,274,100,284,100,96.,.09,1.6,1.8*41.
GEN 223,4,0,274,100,287,100,96.,.06,1.6,1.7*41.
GEN 224,4,0,287,100,286,100,96.,.06,1.2,0.8*41.
GEN 225,4,0,286,100,285,100,96.,.06,1.2,0.8*41.
GEN 226,4,0,285,100,273,100,96.,.06,1.2,0.8*41.
GEN 227,4,0,288,100,289,100,96.,.05,1.6,1.0*41.
GEN 228,4,0,290,100,291,100,96.,.06,1.6,0.8*41.
GEN 229,4,0,290,100,280,100,96.,.06,1.6,0.8*41.
GEN 230,4,0,285,100,290,100,96.,.06,1.0,1.3*41.
GEN 231,4,0,286,100,291,100,96.,.05,0.8,1.3*41.
GEN 232,4,0,287,100,288,100,96.,.05,0.8,1.3*41.
GEN 233,4,0,290,100,201,100,96.,.06,1.1,.75*41.
GEN 234,4,0,291,100,282,100,96.,.05,0.8,1.5*41.
GEN 235,4,0,288,100,282,100,96.,.05,0.8,1.2*41.
GEN 236,4,0,289,100,284,100,96.,.05,0.8,.75*41.
GEN 237,4,0,289,100,274,100,96.,.05,0.8,.75*41.
GEN 238,4,0,284,100,283,100,96.,.06,2.8,1.0*41.
GEN 241,4,0,222,1,   272,1,.625
GEN 341,4,0,322,1,   372,1,.625
GEN 441,4,0,422,1,   472,1,.625
GEN 541,4,0,522,1,   572,1,.625
GEN 242,4,0,212,1,   272,1,.625
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GEN 342,4,0,312,1,  372,1,.625
GEN 442,4,0,412,1,  472,1,.625
GEN 542,4,0,512,1,  572,1,.625
GEN 243,4,0,232,1,  272,1,.647
GEN 343,4,0,332,1,  372,1,.647
GEN 443,4,0,432,1,  472,1,.647
GEN 543,4,0,532,1,  572,1,.647
GEN 244,4,0,242,1,  272,1,.647
GEN 344,4,0,342,1,  372,1,.647
GEN 444,4,0,442,1,  472,1,.647
GEN 544,4,0,542,1,  572,1,.647
GEN 245,2,0,247,1,  281,3,.647
GEN 345,2,0,347,1,  381,3,.647
GEN 445,2,0,447,1,  481,3,.647
GEN 545,2,0,547,1,  581,3,.647
GEN 246,4,0,252,100,292,100, 0.35
GEN 346,4,0,251,100,205,100, 0.35
GEN 247,2,0,253,1,  293,0,0.15
GEN 347,2,0,353,1,  393,0,0.15
GEN 447,2,0,453,1,  493,0,0.15
GEN 547,2,0,553,1,  593,0,0.15
GEN 249,4,0,257,100,289,100,2.,.625,1.,1.
GEN 250,4,0,258,100,290,100,2.,.625,1.,1.
GEN 251,4,0,255,100,288,100,2.,.625,1.,1.
GEN 252,4,0,256,100,291,100,2.,.625,1.,1.
GEN 271,2,0,237,  1,281,  3, .647
GEN 371,2,0,337,  1,381,  3, .647
GEN 471,2,0,437,  1,481,  3, .647
GEN 571,2,0,537,  1,581,  3, .647
GEN 572,4,0,296,100,297,100,96.,.06,1.5,3.5*41.
GEN 573,4,0,296,100,298,100,96.,.06,1.5,3.5*41.
GEN 574,4,0,297,100,298,100,96.,.09,1.0,1.1*41.
GEN 575,4,0,203,100,292,100,96.,.18,1.5,1.6*41.
GEN 576,4,0,204,100,294,100,96.,0.3,.37,.47*41.
GEN 577,4,0,204,100,295,100,96.,0.3,.37,.47*41.
GEN 578,4,0,282,100,261,100,7.6/3.
GEN 579,4,0,292,100,261,100,7.6/3.
GEN 580,4,0,281,100,296,100,1.25
GEN 581,4,0,294,100,297,100,.625
GEN 582,4,0,295,100,298,100,.625
GEN 583,4,0,261,100,262,100,1./.55/1.8
GEN 584,4,0,203,100,293,100, 96.*0.8*.19/0.3/41.
GEN 585,4,0,292,100,204,100, 96.*1.5*.19/.58/41.
GEN 586,4,0,204,100,205,100, 96.*1.5*.19/.58/41.
GEN 587,4,0,201,100,282,100, 96.*.282/.6/41.
GEN 588,4,0,202,100,206,100, 96.*.282/.8/41.
GEN 589,4,0,206,100,284,100, 96.*.282/.9/41.
GEN 590,4,0,201,100,203,100, 10.*.95/1.8
GEN 591,4,0,202,100,292,100, 10.*.95/1.8
GEN 592,4,0,206,100,205,100, 10.*.95/1.8
GEN 593,4,0,201,100,261,100, 7.6/3.
GEN 594,4,0,203,100,261,100, 7.6/3.
GEN 595,4,0,206,100,261,100, 7.6/3.
GEN 596,4,0,205,100,261,100, 7.6/3.
//
```

```
      GEN 597,4,0,285,100,282,100, 96.*.06*1.3/1.7/41.
      GEN 598,4,0,286,100,202,100, 96.*.06*1.3/1.7/41.
      GEN 599,4,0,287,100,206,100, 96.*.06*1.3/1.7/41.
C     TOP ASSEMBLY
      GEN 601,4,0,2,2,888,0,   1.8*.5/.17/1.8
      GEN 602,2,0,37,6,888,0,  1.8*.5/.17/1.8
      GEN 605,4,0,3,2,283,100,  1.75*1.7/.17/1.8
      GEN 606,4,0,  2,  2,275,100, 0.8*1.3/.17/1.8
      GEN 608,4,0, 11,  1,262,100, 2.6
      -151, 78,162, 162,163, 163,20,  .68*2.2*4.0/144./3.413
      GEN -260,4,0,221,100,211,100, 0.56*.66,3.7,4.4,144.*3.413 $F*E
      GEN -261,4,0,221,100,276,100, 0.12*.65,3.7,4.4,144.*3.413
      GEN -262,4,0,221,100,286,100, 0.10*.66,3.7,4.4,144.*3.413
      GEN -263,4,0,221,100,279,100, 0.12*.66,3.7,4.4,144.*3.413
      GEN -264,4,0,221,100,279,100, 0.10*.66,3.7,4.4,144.*3.413
      GEN -265,4,0,211,100,276,100, 0.10*.66,3.7,4.4,144.*3.413
      GEN -266,4,0,211,100,286,100, 0.12*.66,3.7,4.4,144.*3.413
      GEN -267,4,0,211,100,279,100, 0.10*.66,3.7,4.4,144.*3.413
      GEN -268,4,0,211,100,279,100, 0.12*.66,3.7,4.4,144.*3.413
      GEN -269,4,0,211,100,236,100, 1.00*.66,3.7,4.4,144.*3.413
      GEN -270,4,0,221,100,249,100, 1.00*.66,3.7,4.4,144.*3.413
      GEN -612,3,0,246,100,387,100,       .66,4.00,4.00,144.*3.413
      GEN -613,3,0,241,100,331,100,       .66,4.00,4.00,144.*3.413
      GEN -617,4,0,276,100,999,0,         .80,1.72,4.00,144.*3.413
      GEN -618,4,0,282,100,999,0,         .80,1.72,4.00,144.*3.413
      -625, 287,888, 231,888,           .21*.19*4.00*4.00/144./3.413
      -626, 287,999, 231,999,           .79*.66*4.00*4.00/144./3.413
      -627, 541,888, 546,888,           .22*.19*4.00*4.00/144./3.413
      -628, 541,999, 546,999,           .79*.56*4.00*4.00/144./3.413
      GEN -631,4,0,296,100,888,0,     .15*.19,1.72,4.00,144.*3.413
      GEN -632,4,0,236,100,999,0,     .85*.66,1.72,4.00,144.*3.413
      GEN-635,4,0,279,100,888,   0, .15*.19,1.72,4.00,144.*3.413
      GEN-636,4,0,279,100,999,   0, .85*.66,1.72,4.00,144.*3.413
      END
//
```

APPENDIX C

Program Control and Power Dissipation

```
        BCD 3CONSTANTS DATA
        NDSTOR#1000,ITERMX#1000
        ARLXCA#.002,DRLXCA#.002
        ABSZRO#-460.0,SBCNST#.171E-8
        1#1.0
        2#1.0
        3#1.0
        4#1.0
        5#1.0
        6#0.
        END
        BCD 3ARRAY DATA
        END
        BCD 3EXECUTION
C       HOT
C       TEST CONDITION
        T999#80.0
        STDSTL
        END
        BCD 3VARIABLES1
        Q141#1.2     *R1
        Q142#1.2     *R1
        Q143#1.2     *R1
        Q147#0.03    *R1
        Q148#0.03    *R1
        Q149#0.03    *R1
        Q162#1.108*R1*R6
        Q163#1.898   *R1
        Q164#1.6     *R1
        Q165#1.6     *R1
        Q166#0.6     *R1
        Q167#7.9     *R1
C       RELAYS
        Q 169#.6*2.*R1   *R6
        Q 170#.6*2.*R1   *R6
C       DISCRETE PARTS ON A2 %WAS A4<
        Q171#.393*R1             %Q2
        Q172#.425*R1             %Q5
        Q173#.425*R1             %Q7
        Q174#.640 *R1            %R4
        Q175#.342 *R1            %R14
        Q176#0.504   *R1
        Q211#1.573   *R2
        Q221#0.858   *R2
        Q251#2.56    *R2
        Q252#2.56    *R2
        Q253#1.7     *R2
        Q254#1.7     *R2
        Q255#0.075   *R2
        Q256#0.075   *R2
        Q257#1.4     *R2
        Q258#0.6     *R2
        Q284#0.01    *R2
        Q285#0.01    *R2
        Q311#1.573   *R3
//
```

```
        Q321#0.956   #R3
        Q351#4.65    #R3
        Q352#4.65    #R3
        Q353#2.8     #R3
        Q354#2.8     #R3
        Q355#0.15    #R3
        Q356#0.15    #R3
        Q357#1.8     #R3
        Q358#0.95    #R3
        Q384#0.01    #R3
        Q385#0.01    #R3
        Q411#1.573   #R4
        Q421#0.956   #R4
        Q451#4.65    #R4
        Q452#4.65    #R4
        Q453#2.8     #R4
        Q454#2.8     #R4
        Q455#0.15    #R4
        Q456#0.15    #R4
        Q457#1.8     #R4
        Q458#0.95    #R4
        Q484#0.01    #R4
        Q485#0.01    #R4
        Q511#1.573   #R5
        Q521#0.986   #R5
        Q551#4.7     #R5
        Q552#4.7     #R5
        Q553#1.5     #R5
        Q554#1.5     #R5
        Q555#0.16    #R5
        Q556#0.16    #R5
        Q557#1.3     #R5
        Q558#1.0     #R5
        Q584#0.01    #R5
        Q585#0.01    #R5
        END
        BCD 3OUTPUT CALLS
F       WRITE%6,1<
F1      FORMAT%5X,*TEMPERATURE IN DEGREES FAHRENHEIT*<
             TPRINT
C       PRINT OUT TEMPERATURES IN DEGREES CELSIUS
F       NTOT#NNT
F       DO100  I#1, NTOT
F       T%I<#%T%I< & 40.</1.8-40.
F100    CONTINUE
F       WRITE%6,2<
F2      FORMAT%5X,*TEMPERATURE IN DEGREES CELSIUS*<
        TPRINT
F       NTOT#NNT
F       DO 200 I#1, NTOT
//
```

```
F       TST<#STST<540.<#1.9-40.
F200    CONTINUE
        END
C       INITIAL RUN WAS WITH RELAYS OFF
        BCD 3FINAL PARAMETERS
        BCD 3TITLE DATA
        BCD 9TURN ON RELAYS
        END
        BCD 3CONSTANTS DATA
        6#1.0
        END
        BCD 3FINAL PARAMETERS
        BCD 3TITLE DATA
        BCD 9MODIFY PC BOARD 3
        END
        BCD 3CONDUCTOR DATA
        108#.0016    S2#G108
        109#.0016    S2#G109
        END
        BCD 3FINAL PARAMETERS
        BCD 3TITLE DATA
        BCD 9TURN OFF RELAYS
        END
        BCD 3CONSTANTS DATA
        6#0.0
        END
        BCD 3END OF DATA
//
```

APPENDIX D

Temperature Summary

Unit P.S. - MSFC
Board Input Electronics (A1)
Max. Av. Bd. Temp °C (°F)

Averaged DB Dissip -1.898
Heat Sunk Dissip -18.269
Total Dissipation -20.167

Run - Node -						Temperatures, °C Normal PC Board Conductance				Increased PC Board Conductance			
Part Type	Ref Des	Node No.	Ambient Sink or Junction Temp	Heat Dissip, watts		Relays Off		Relays On		Relays Off		Relays On	
Board	(A1, A2)	162	AMB	0	1.188 with Relays On	71		92		63		83	
Board	A3	163	AMB	1.898		84		94		75		84	
Filter	FL1	164	Case	1.6		50		51		50		51	
Filter	FL2	165	Case	1.6		49		50		49		50	
Transformer	T1	166	Case	0.6		41		41		41		41	
2N4900	Q1	167	Case	7.9		52		52		52		52	
Input Filter	A5	--	Case	(Total 3.84)									
Choke	L1	141	Case	1.2		85		85		85		85	
Choke	L2	142	Case	1.2		86		87		86		87	
Choke	L3	143	Case	1.2		82		82		82		82	
Caps	C1 - C4	147	Case	0.08		81		82		81		82	
Caps	C1 - C4	148	Case	0.08		85		86		85		86	
Caps	C1 - C4	149	Case	0.08		79		79		79		79	
Relays	K1 & K2	169	Sink	0	1.2 with Relay On	46		77		47		78	
Relays	K3 & K4	170	Sink	0	1.2 with Relay On	45		76		46		77	
2N5682	Q2	171	Sink	0.393		64		71		65		71	
2N5680	Q5	172	Sink	0.425		65		72		66		73	
2N5680	Q7	173	Sink	0.425		63		69		63		69	
RWR89	R4	174	Sink	0.64		72		78		72		79	
RCR07	R14	175	Sink	0.342		59		65		70		66	

Unit - P.S. - MSFC
O/R Module A2 +5V
Max. Av. BD. Temp °C (°F)

Average DB Dissip -2.431
Heat Sunk Dissip -
Total Dissipation -13.121

Run - Node -						Temperatures, °C Normal PC Board Conductance				Increased PC Board Conductance			
Part Type	Ref Des	Node No.	Ambient Sink or Junction Temp	Heat Dissip, watts		Relays Off		Relays On		Relays Off		Relays On	
Board	A1	211	AMB	1.573	2.173 with Relay On	59		59		59		59	
Board	A2	221	AMB	0.858		54		54		54		54	
2N3716	Q1	252	Case	2.56	TO-3 θ = 1.7	48		48		48		48	
	Q2	251	Case	2.56		48		48		48		48	
	T1	256	Case	0.075		44		44		44		44	
	T2	255	Case	0.075		44		44		44		44	
	T3	257	Case	1.4		45		45		45		45	
	L1	258	Case	0.6		44		44		44		44	
	CR1	253	Case	1.7		52		52		52		52	
	CR2	254	Case	1.7		52		52		52		52	
	R1	284	AMB	0.01		41		42		41		42	
	R2	285	AMB	0.01		43		43		43		43	
Board A2													
Ref Module	U5			0.35									

Unit - P.S. - MSFC
O/R Module A3 ±15V
Max. Av. BD Temp °C (°F)

Averaged BD Dissip -2.529
Heat Sunk Dissip -
Total Dissipation -20.499

Run - Node						Temperatures, °C Normal PC Board Conductance				Increased PC Board Conductance			
Part Type	Ref Des	Node No.	Ambient Sink or Junction Temp	Heat Dissip, watts		Relays Off		Relays On		Relays Off		Relays On	
Board	A1	311	AMB	1.573	2.173 with Relay on	62		62		62		62	
Board	A2	321	AMB	0.956		58		58		58		58	
2N3716	Q1	352	Case	4.65		56		56		56		56	
	Q2	351	Case	4.65		56		56		56		56	
	T1	356	Case	0.15		48		49		48		49	
	T2	355	Case	0.15		49		49		49		49	
	T3	357	Case	1.8		50		50		50		50	
	L1	358	Case	0.95		49		49		49		49	
	CR1	353	Case	2.8		61		62		61		62	
	CR2	354	Case	2.8		61		62		61		62	
	R1	384	AMB	0.01		45		45		45		45	
	R2	385	AMB	0.01		47		47		47		47	
Board A2 Ref Module	U5			0.[illegible]5									

Unit - P.S. - MSFC
O/R Module A4 +15V
Max. Av. BD. Temp °C (°F)

Averaged BD Dissip -2.529
Heat Sunk Dissip -
Total Dissipation -20.499

Run Node						Temperature, °C Normal PC Board Conductance				Increased PC Board Conductance			
Part Type	Ref Des	Node No.	Ambient Sink or Junction Temp	Heat Dissip, watts		Relays Off		Relays On		Relays Off		Relays On	
Board	A1	411	AMB	1.573	2.173 with Relay On	62		62		62		62	
Board	A2	421	AMB	0.956		58		58		58		58	
2N3716	Q1	452	Case	4.65		56		56		56		56	
	Q2	451	Case	4.65		55		56		55		56	
	T1	456	Case	0.15		48		49		48		49	
	T2	455	Case	0.15		49		49		49		49	
	T3	457	Case	1.8		50		50		50		50	
	L1	458	Case	0.95		49		49		49		49	
	CR1	453	Case	2.8		61		62		61		62	
	CR2	454	Case	2.8		61		62		61		62	
	R1	484	AMB	0.01		45		45		45		45	
	R2	485	AMB	0.01		47		47		47		47	
Board A2													
Ref Module	U5			0.35									

Unit - P.S. - MSFC
O/R Module A5 +28V
Max. Av. BD Temp °C (°F)

Averaged BD Dissip -2.559
Heat Sunk Dissip -
Total Dissipation -18.099

Run - Node -						Temperature, °C Normal PC Board Conductance				Increased PC Board Conductance			
Part Type	Ref Des	Node No.	Ambient Sink or Junction Temp	Heat Dissip, watts		Relays Off		Relays On		Relays Off		Relays On	
Board	A1	511	AMB	1.573	2.173 with Relay On	62		62		62		62	
Board	A2	521	AMB	0.986		57		58		57		58	
2N3716	Q1	552	Case	4.7		55		56		55		56	
"	Q2	551	Case	4.7		55		56		55		56	
	T1	556	Case	0.16		48		48		48		48	
	T2	555	Case	0.16		48		48		48		48	
	T3	557	Case	1.8		49		49		49		49	
	L1	558	Case	1.0		48		48		48		48	
	CR1	553	Case	1.5		54		55		55		55	
	CR2	554	Case	1.5		54		55		55		55	
	R1	584	AMB	0.01		44		45		45		45	
	R2	585	AMB	0.01		46		47		46		47	
Board A2													
Ref Module	U5			0.35									

APPENDIX E

Complete Temperature Listing

Relays OFF in Input Electronics

Normal PC Board Conductance in Input Electronics

TEMPERATURE IN DEGREES CELSIUS

```
TIMEN  = 0.                  EBALSC          = 0.              CSGMIN
TSTEPU = 0.                  EBALNC(     0)  = 0.              CSGMAX
                             ITERCT          =       272       DMXTCC

                                                               DIFFUSIO
                                                                     ++
                                                               ARITHMET
 T      1=   36.6143     T      2=   34.9611     T      3=   36.6819
 T      7=   37.7695     T      8=   36.1560     T      9=   38.0842
 T     13=   40.5294     T     14=   41.8966     T     15=   38.1156
 T     19=   40.5439     T     20=   41.1496     T     21=   40.5922
 T     25=   39.5203     T     26=   40.5363     T     27=   39.0247
 T     31=   37.0442     T     32=   36.9317     T     33=   36.7274
 T     37=   33.0195     T     38=   33.5734     T     39=   33.6961
 T     43=   33.0336     T     44=   33.7937     T     45=   39.4315
 T     54=   40.6894     T     55=   39.2947     T     56=   37.5820
 T     72=   36.6809     T     73=   38.1964     T     74=   41.0372
 T     78=   38.8209     T     79=   38.8532     T     80=   37.0371
 T     84=   35.7107     T     85=   34.4041     T     86=   34.3648
```

```
(      0) = 0.                DRLXCC(      0) = 0.
(      0) = 0.                ARLXCC(    394) = 1.765944E-03
(      0) = 0.                AMXTCC(      0) = 0.

N NODES
NONE++
IC NODES
 T      4=   35.9465     T      5=   37.7731     T      6=   36.1562
 T     10=   43.2659     T     11=   39.8617     T     12=   40.9279
 T     16=   38.6530     T     17=   40.2575     T     18=   41.0961
 T     22=   39.2167     T     23=   39.7815     T     24=   40.0808
 T     28=   38.8526     T     29=   40.0471     T     30=   39.0576
 T     34=   36.6300     T     35=   37.4152     T     36=   35.3041
 T     40=   33.6932     T     41=   33.6904     T     42=   33.5696
 T     51=   44.3985     T     52=   43.4991     T     53=   40.2600
 T     57=   37.6910     T     58=   37.4326     T     71=   37.1258
 T     75=   39.3382     T     76=   38.0630     T     77=   38.8897
 T     81=   35.7591     T     82=   35.6618     T     83=   35.5928
 T     87=   34.2158     T     88=   36.7667     T    141=   85.2163
```

DATE 03/24/76 TIME 12.56.44. MARTIN MARIETTA THERMAL ANALYZER SY

POWER SUPPLY - MSFC

T	142=	96.4885	T	143=	92.0699	T	144=	90.1710
T	148=	85.4795	T	149=	78.5840	T	150=	76.9384
T	154=	37.3062	T	155=	37.9726	T	156=	40.8179
T	165=	49.4250	T	166=	40.7908	T	167=	51.5468
T	171=	64.0666	T	172=	65.4164	T	173=	62.8793
T	181=	47.3276	T	182=	44.7130	T	183=	45.1179
T	187=	45.0905	T	188=	44.8895	T	189=	47.4626
T	193=	47.4895	T	194=	44.6981	T	195=	44.9529
T	199=	41.3337	T	200=	42.1993	T	201=	43.4986
T	205=	43.5056	T	206=	43.2946	T	211=	59.0167
T	215=	35.5325	T	221=	54.2079	T	222=	39.9397
T	231=	40.5059	T	232=	40.0476	T	233=	41.5477
T	237=	43.1685	T	238=	41.4060	T	239=	41.3450
T	244=	41.4916	T	245=	36.5838	T	246=	41.8759
T	251=	47.5691	T	252=	47.7487	T	253=	51.5801
T	257=	44.8256	T	258=	43.7843	T	261=	43.3490
T	274=	41.5652	T	275=	35.5286	T	276=	40.5923
T	281=	43.3665	T	282=	43.4197	T	283=	36.8659
T	287=	42.1621	T	288=	43.7590	T	289=	44.2033
T	293=	45.2938	T	294=	43.5532	T	295=	43.5532
T	301=	49.1674	T	302=	48.3829	T	303=	48.4775
T	311=	62.0023	T	312=	42.7969	T	313=	45.6308
T	322=	42.7962	T	323=	45.6301	T	324=	45.2302
T	333=	45.2699	T	334=	44.9736	T	335=	38.1172
T	339=	45.0198	T	341=	43.8612	T	342=	43.0012
T	346=	45.1275	T	347=	47.6959	T	348=	44.9656
T	353=	61.4705	T	354=	61.4705	T	355=	48.5751
T	361=	47.8877	T	362=	42.8752	T	372=	42.7936
T	376=	43.7758	T	378=	41.6890	T	379=	39.7938
T	383=	38.0521	T	384=	44.9479	T	385=	47.1400
T	389=	48.8155	T	390=	48.3218	T	391=	48.3474
T	395=	48.3127	T	396=	47.8498	T	397=	48.2717
T	403=	48.3295	T	404=	48.2140	T	405=	48.0923
T	413=	45.6370	T	414=	45.2832	T	415=	36.9258
T	424=	45.2925	T	425=	36.9251	T	431=	44.0877
T	435=	38.3144	T	436=	44.3575	T	437=	47.5697
T	442=	43.0914	T	443=	45.2796	T	444=	45.0165
T	448=	44.9084	T	449=	44.0971	T	451=	55.4732
T	455=	48.5705	T	456=	48.3342	T	457=	49.6115
T	472=	42.8982	T	473=	45.6343	T	474=	45.2804
T	479=	39.9395	T	480=	46.9111	T	481=	47.8392
T	485=	47.1948	T	486=	47.5705	T	487=	47.0534
T	491=	48.2675	T	492=	48.3790	T	493=	50.9520
T	497=	48.1290	T	498=	48.1290	T	501=	47.3053
T	505=	47.5687	T	506=	47.2292	T	511=	61.6008
T	515=	36.8640	T	521=	57.2827	T	522=	42.1148
T	531=	43.5068	T	532=	42.3833	T	533=	44.5296
T	537=	46.8513	T	538=	44.4835	T	539=	44.4614
T	544=	44.0829	T	545=	37.9528	T	546=	43.1932
T	551=	55.0290	T	552=	55.2821	T	553=	54.4615
T	557=	49.0550	T	558=	48.0169	T	561=	47.2009
T	574=	44.5654	T	575=	36.9598	T	576=	43.0540
T	581=	47.1107	T	582=	47.3024	T	583=	38.3331
T	587=	46.4657	T	588=	47.9499	T	589=	48.2550

T 145=	86.4885	T 146=	92.0699	T 147=	81.4287
T 151=	84.5441	T 152=	74.2460	T 153=	39.9103
T 162=	79.7313	T 163=	83.6156	T 164=	50.3244
T 168=	40.7993	T 169=	46.2227	T 170=	44.7999
T 174=	71.6940	T 175=	59.3235	T 176=	71.0113
T 184=	44.8367	T 185=	47.3544	T 186=	44.7106
T 190=	44.7006	T 191=	44.9798	T 192=	44.8958
T 196=	44.8976	T 197=	41.2371	T 198=	39.5966
T 202=	43.5992	T 203=	43.6916	T 204=	43.5817
T 212=	39.3405	T 213=	41.8242	T 214=	41.5682
T 223=	41.8234	T 224=	41.5674	T 225=	35.5317
T 234=	41.3580	T 235=	36.4958	T 236=	40.7738
T 241=	41.9574	T 242=	40.1356	T 243=	41.6713
T 247=	43.2205	T 248=	41.4580	T 249=	41.1459
T 254=	51.5801	T 255=	43.7924	T 256=	43.5370
T 262=	40.9374	T 272=	39.9373	T 273=	41.8213
T 278=	39.2991	T 279=	37.8004	T 280=	42.6526
T 284=	41.4126	T 285=	42.7571	T 286=	42.9386
T 290=	43.5178	T 291=	43.5935	T 292=	43.6852
T 296=	43.3555	T 297=	43.5279	T 298=	43.5279
T 304=	48.3585	T 305=	48.2354	T 306=	47.8858
T 314=	45.2309	T 315=	36.7267	T 321=	57.8268
T 325=	36.7260	T 331=	43.9980	T 332=	43.0083
T 336=	44.1687	T 337=	47.5853	T 338=	44.9550
T 343=	45.2719	T 344=	44.9757	T 345=	38.1100
T 349=	44.0659	T 351=	55.6154	T 352=	55.9069
T 356=	48.4141	T 357=	49.6155	T 358=	48.7432
T 373=	45.6281	T 374=	45.2280	T 375=	36.7224
T 380=	46.9318	T 381=	47.9746	T 382=	48.0324
T 386=	47.5651	T 387=	46.9050	T 388=	48.5082
T 392=	48.5259	T 393=	51.1000	T 394=	48.3122
T 399=	48.2720	T 401=	48.0231	T 402=	48.2398
T 406=	47.7401	T 411=	62.1138	T 412=	42.9015
T 421=	57.8899	T 422=	42.9008	T 423=	45.6363
T 432=	43.1204	T 433=	45.3138	T 434=	45.0516
T 438=	44.9986	T 439=	45.0866	T 441=	43.8918
T 445=	39.2763	T 446=	45.0846	T 447=	47.5695
T 452=	55.7680	T 453=	61.3223	T 454=	61.3223
T 458=	48.6563	T 461=	47.7321	T 462=	42.5447
T 475=	34.9215	T 476=	43.8294	T 478=	41.8138
T 482=	47.3879	T 483=	38.0464	T 484=	44.8892
T 488=	48.5038	T 489=	48.8116	T 490=	48.2340
T 494=	48.1699	T 495=	48.1689	T 496=	47.7149
T 502=	47.6829	T 503=	47.5011	T 504=	47.6665
T 512=	42.1155	T 513=	44.7866	T 514=	44.5682
T 523=	44.7859	T 524=	44.5675	T 525=	36.8632
T 534=	44.3578	T 535=	39.1518	T 536=	43.7764
T 541=	42.4333	T 542=	42.1844	T 543=	44.2446
T 547=	46.7271	T 548=	44.3593	T 549=	42.6983
T 554=	54.4615	T 555=	48.0210	T 556=	47.7080
T 562=	43.3807	T 572=	42.1123	T 573=	44.7837
T 578=	41.4158	T 579=	39.5254	T 580=	46.1757
T 584=	44.4859	T 585=	46.4051	T 586=	46.9440
T 590=	47.5725	T 591=	47.6368	T 592=	47.8217
T 593=	48.9059	T 594=	47.6068	T 595=	47.6063
T 596=	47.0055	T 597=	47.5540	T 598=	47.5540

BOUNDARY NODES

T 888= 32.2222 T 999= 26.6667 T

APPENDIX F

Complete Temperature Listing

Relays ON in Input Electronics

Normal PC Board Conductance in Input Electronics

TEMPERATURE IN DEGREES CELSIUS

```
TTIMEN  = 0.          EPSLON            = 0.              CSGMIN
TSTEPN  = 0.          RELXCC(       0)  = 0.              CSGMAX
                      ITERCT            =        111      DAXTCC

                                                          DIFFUSIO
                                                                ++
                                                          ARITHMET
```

T	1=	36.7311	T	2=	35.9159	T	3=	36.7447
T	7=	37.9793	T	8=	36.3356	T	9=	38.3742
T	13=	45.3277	T	14=	42.5747	T	15=	38.3519
T	19=	41.3743	T	20=	42.1173	T	21=	41.5596
T	25=	40.2249	T	26=	41.3757	T	27=	40.2810
T	31=	37.2062	T	32=	37.3071	T	33=	37.2024
T	37=	33.9936	T	38=	33.7171	T	39=	33.8624
T	43=	33.1966	T	44=	34.9599	T	45=	40.6332
T	54=	41.0373	T	55=	39.5970	T	56=	37.2332
T	72=	36.9272	T	73=	39.2409	T	74=	41.7213
T	78=	40.2685	T	79=	41.0310	T	80=	37.3240
T	84=	35.3937	T	85=	34.6457	T	86=	34.7136

```
(        0) = 0.          DRLXCC(       0) = 0.
(        0) = 0.          ARLXCC(     191) = 1.443430E-03
(        0) = 0.          AMXTCC(       0) = 0.
```

N NODES
NONE++
IC NODES

T	4=	36.0506	T	5=	37.9363	T	6=	36.2919
T	10=	43.5594	T	11=	40.0244	T	12=	41.2615
T	16=	39.4702	T	17=	40.7295	T	18=	41.7801
T	22=	39.4914	T	23=	40.1222	T	24=	40.5106
T	28=	39.1394	T	29=	40.3645	T	30=	39.3870
T	34=	37.1273	T	35=	37.6571	T	36=	35.4686
T	40=	33.8705	T	41=	33.3797	T	42=	33.7578
T	51=	44.7630	T	52=	43.8274	T	53=	40.6767
T	57=	37.9405	T	58=	37.7918	T	71=	37.3573
T	75=	39.7979	T	76=	38.7705	T	77=	40.0234
T	81=	36.1503	T	82=	36.2727	T	83=	36.1907
T	87=	34.5507	T	88=	36.9323	T	141=	85.4469

DATE 03/24/76 TIME 12.57.37. MARTIN MARIETTA THERMAL ANALYZER SY

TURN ON RELAYS

T	142=	86.6978	T	143=	82.2581	T	144=	80.4239
T	148=	85.6887	T	149=	78.7693	T	150=	77.1746
T	154=	37.4447	T	155=	38.0581	T	156=	41.2445
T	165=	49.7533	T	166=	41.2618	T	167=	51.8404
T	171=	70.6108	T	172=	71.9606	T	173=	68.5941
T	181=	57.0310	T	182=	54.3947	T	183=	54.1009
T	187=	53.5314	T	188=	53.6172	T	189=	54.5308
T	193=	54.0335	T	194=	51.1963	T	195=	50.6672
T	199=	42.2094	T	200=	43.4157	T	201=	43.6182
T	205=	43.6252	T	206=	43.4135	T	211=	59.0917
T	215=	35.5917	T	221=	54.2897	T	222=	40.0273
T	231=	40.5920	T	232=	40.1351	T	233=	41.6476
T	237=	43.2846	T	238=	41.5103	T	239=	41.4426
T	244=	41.5808	T	245=	36.6503	T	246=	41.9849
T	251=	47.6887	T	252=	47.8689	T	253=	51.7001
T	257=	44.9298	T	258=	43.8975	T	261=	43.4707
T	274=	41.6640	T	275=	35.5877	T	276=	40.6829
T	281=	43.4847	T	282=	43.5400	T	283=	36.9493
T	287=	42.2660	T	288=	43.8664	T	289=	44.3077
T	293=	45.4040	T	294=	43.6724	T	295=	43.6724
T	301=	48.4090	T	302=	48.6256	T	303=	48.7206
T	311=	62.1450	T	312=	42.9557	T	313=	45.8265
T	322=	42.9550	T	323=	45.8258	T	324=	45.4204
T	333=	45.4600	T	334=	45.1597	T	335=	38.2384
T	339=	45.2096	T	341=	44.0338	T	342=	43.1627
T	346=	45.3219	T	347=	47.9294	T	348=	45.1725
T	353=	61.7132	T	354=	61.7132	T	355=	48.7900
T	361=	48.1341	T	362=	43.1845	T	372=	42.9526
T	376=	43.9444	T	378=	41.8401	T	379=	39.9246
T	383=	38.2171	T	384=	45.1564	T	385=	47.3571
T	389=	49.0218	T	390=	48.5474	T	391=	48.5757
T	395=	48.5542	T	396=	48.0863	T	397=	48.5131
T	403=	48.5747	T	404=	48.4588	T	405=	48.3371
T	413=	45.8501	T	414=	45.4963	T	415=	37.0672
T	424=	45.4956	T	425=	37.0665	T	431=	44.2803
T	435=	38.4658	T	436=	44.5502	T	437=	47.8084
T	442=	43.2815	T	443=	45.4910	T	444=	45.2289
T	448=	45.1363	T	449=	44.2999	T	451=	55.7181
T	455=	48.7981	T	456=	48.5677	T	457=	49.8350
T	472=	43.0850	T	473=	45.8475	T	474=	45.4934
T	479=	40.0987	T	480=	47.1365	T	481=	48.0811
T	485=	47.3324	T	486=	47.8011	T	487=	47.2799
T	491=	48.5012	T	492=	48.6247	T	493=	51.1971
T	497=	48.3728	T	498=	48.3728	T	501=	47.7997
T	505=	48.0631	T	506=	47.7188	T	511=	61.8693
T	515=	37.0476	T	521=	57.5557	T	522=	42.4085
T	531=	43.8251	T	532=	42.6817	T	533=	44.8972
T	537=	47.3259	T	538=	44.8887	T	539=	44.8309
T	544=	44.4370	T	545=	38.1601	T	546=	43.5385
T	551=	55.5234	T	552=	55.7809	T	553=	54.9589
T	557=	49.4640	T	558=	48.4740	T	561=	47.7045
T	574=	44.9319	T	575=	37.0433	T	576=	43.3739
T	581=	47.5967	T	582=	47.7993	T	583=	38.6278
T	587=	46.8863	T	588=	48.3803	T	589=	48.6637

T	145=	86.6978	T	146=	92.2581	T	147=	81.6613
T	151=	84.7531	T	152=	74.4272	T	153=	40.1843
T	162=	91.8914	T	163=	93.8765	T	164=	50.6889
T	168=	41.2618	T	169=	77.2585	T	170=	75.9671
T	174=	78.1321	T	175=	65.3449	T	176=	92.1714
T	184=	54.1538	T	185=	56.5338	T	186=	53.8642
T	190=	51.7267	T	191=	51.2357	T	192=	51.4555
T	196=	50.9101	T	197=	43.1008	T	198=	41.3810
T	202=	43.7190	T	203=	43.8118	T	204=	43.7013
T	212=	40.0281	T	213=	41.9275	T	214=	41.6670
T	223=	41.0247	T	224=	41.6662	T	225=	35.5909
T	234=	41.4566	T	235=	36.5694	T	236=	40.8608
T	241=	41.0541	T	242=	40.2250	T	243=	41.7739
T	247=	43.3377	T	248=	41.5634	T	249=	41.2425
T	254=	51.7001	T	255=	43.8997	T	256=	43.6497
T	271=	40.9897	T	272=	40.0246	T	273=	41.9243
T	278=	39.2105	T	279=	37.4715	T	280=	42.7623
T	284=	41.5176	T	285=	42.8669	T	286=	43.0483
T	290=	43.6304	T	291=	43.5164	T	292=	43.8055
T	296=	43.3829	T	297=	42.6469	T	298=	43.6670
T	304=	42.6069	T	305=	48.4774	T	306=	48.1260
T	314=	45.4211	T	315=	36.8369	T	321=	57.9766
T	325=	34.9362	T	331=	44.0651	T	332=	43.1688
T	336=	44.3358	T	337=	47.9184	T	338=	45.1615
T	343=	48.4634	T	344=	45.1631	T	345=	38.2323
T	350=	44.2304	T	351=	55.8584	T	352=	56.1505
T	356=	40.6427	T	357=	49.8217	T	358=	48.9699
T	373=	45.9239	T	374=	45.4184	T	375=	36.8327
T	380=	47.1302	T	381=	48.2127	T	382=	48.2756
T	386=	47.7351	T	387=	47.1152	T	388=	48.7231
T	392=	42.7606	T	393=	51.3430	T	394=	48.5542
T	398=	43.3131	T	401=	48.2673	T	402=	48.4848
T	406=	47.9331	T	411=	62.2777	T	412=	43.0885
T	421=	58.3623	T	422=	43.0878	T	423=	45.8493
T	432=	43.3176	T	433=	45.5229	T	434=	45.2608
T	438=	45.1368	T	439=	45.2966	T	441=	44.0947
T	445=	39.4207	T	446=	45.3122	T	447=	47.8099
T	452=	54.0056	T	453=	61.5673	T	454=	61.5673
T	459=	40.3908	T	461=	47.9794	T	462=	42.8287
T	475=	37.0630	T	476=	44.0196	T	478=	41.9919
T	482=	40.1331	T	483=	38.2569	T	484=	45.1173
T	488=	43.7316	T	489=	49.0352	T	490=	48.4666
T	494=	40.4131	T	495=	48.4131	T	496=	47.9550
T	502=	48.1795	T	503=	47.9985	T	504=	48.1628
T	512=	42.4092	T	513=	45.1659	T	514=	44.9350
T	523=	45.1452	T	524=	44.9343	T	525=	37.0468
T	534=	44.7261	T	535=	38.3615	T	536=	44.0946
T	541=	42.7890	T	542=	42.4804	T	543=	44.6081
T	547=	47.1304	T	548=	44.7621	T	549=	43.0041
T	554=	54.0509	T	555=	49.4517	T	556=	48.1692
T	562=	44.0100	T	572=	42.4058	T	573=	45.1634
T	578=	41.6923	T	579=	39.7574	T	580=	46.6091
T	584=	44.9949	T	585=	46.8384	T	586=	47.3861
T	590=	40.0294	T	591=	48.0979	T	592=	48.3203
T	593=	49.4334	T	594=	46.1023	T	595=	48.1023
T	596=	47.4865	T	597=	49.0485	T	598=	48.0484

BOUNDARY NODES

T	888=	32.2222	T	893=	26.6667	T

APPENDIX G

Complete Temperature Listing

Relay OFF in Input Electronics

Increased PC Board Conductance in Input Electronics

```
TEMPERATURE IN DEGREES CELSIUS


TIMEN   = 0.                 EBALSC            = 0.                  CSGMIN
TSTEPU  = 0.                 EBALNC(      0)   = 0.                  CSGMAX
                             ITERCT            =        183          DMXTCC

                                                                    DIFFUSIO
                                                                          ++
                                                                    ARITHMET
 T     1=  36.6142      T     2=  34.9626      T     3=  36.6852
 T     7=  37.7713      T     8=  36.2001      T     9=  38.1164
 T    13=  40.5220      T    14=  41.9795      T    15=  38.1161
 T    19=  40.4938      T    20=  40.8861      T    21=  40.6089
 T    25=  39.5501      T    26=  40.6149      T    27=  39.1070
 T    31=  37.0451      T    32=  36.9449      T    33=  36.6993
 T    37=  33.0166      T    38=  33.5661      T    39=  33.6883
 T    43=  33.0293      T    44=  33.7963      T    45=  39.3983
 T    54=  40.6836      T    55=  39.2867      T    56=  37.5725
 T    72=  36.6741      T    73=  38.1752      T    74=  41.0973
 T    78=  38.6049      T    79=  38.8670      T    80=  37.0222
 T    84=  35.7021      T    85=  34.3878      T    86=  34.3330




(       0) = 0.              DRLXCC(      0) = 0.
(       0) = 0.              ARLXCC(    547) =-1.885726E-03
(       0) = 0.              AMXTCC(      0) = 0.

N NODES
NONE++
IC NODES
  T     4=  35.9527      T     5=  37.7873      T     6=  36.1623
  T    10=  43.2855      T    11=  39.8702      T    12=  40.9622
  T    16=  38.6582      T    17=  40.2677      T    18=  41.1020
  T    22=  39.2143      T    23=  39.7823      T    24=  40.0897
  T    28=  38.8463      T    29=  40.0433      T    30=  39.0593
  T    34=  36.5109      T    35=  37.4067      T    36=  35.2974
  T    40=  33.6841      T    41=  33.6798      T    42=  33.5584
  T    51=  44.3834      T    52=  43.4885      T    53=  40.2383
  T    57=  37.6808      T    58=  37.4205      T    71=  37.1109
  T    75=  39.3124      T    76=  38.0122      T    77=  38.8016
  T    81=  35.7282      T    82=  35.5966      T    83=  35.5723
  T    87=  34.2130      T    88=  36.7646      T   141=  85.2184
```

DATE 03/24/76 TIME 12.59.04. MARTIN MARIETTA THERMAL ANALYZER SY

TURN OFF RELAYS

T 142=	86.4906	T 143=	82.0719	T 144=	80.1738
T 148=	85.4817	T 149=	78.5858	T 150=	76.9396
T 154=	37.3062	T 155=	37.9758	T 156=	40.8267
T 165=	49.4144	T 166=	40.8010	T 167=	51.5664
T 171=	64.6139	T 172=	65.9636	T 173=	63.4291
T 181=	48.1075	T 182=	45.6035	T 183=	45.9292
T 187=	45.8583	T 188=	45.7306	T 189=	48.0484
T 193=	48.0366	T 194=	45.3175	T 195=	45.5022
T 199=	41.4967	T 200=	42.4106	T 201=	43.5035
T 205=	43.5104	T 206=	43.2995	T 211=	59.0196
T 215=	35.5343	T 221=	54.2110	T 222=	39.9426
T 231=	40.5084	T 232=	40.0507	T 233=	41.5515
T 237=	43.1732	T 238=	41.4102	T 239=	41.3489
T 244=	41.4858	T 245=	36.5859	T 246=	41.8808
T 251=	47.5739	T 252=	47.7536	T 253=	51.5851
T 257=	44.8297	T 258=	43.7887	T 261=	43.3540
T 274=	41.5694	T 275=	35.5303	T 276=	40.5956
T 281=	43.3713	T 282=	43.4246	T 283=	36.8692
T 287=	42.1663	T 288=	43.7633	T 289=	44.2075
T 293=	45.2887	T 294=	43.5579	T 295=	43.5579
T 301=	48.1881	T 302=	48.4040	T 303=	48.4984
T 311=	62.0135	T 312=	42.8096	T 313=	45.6473
T 322=	42.8089	T 323=	45.6466	T 324=	45.2459
T 333=	45.2857	T 334=	44.9888	T 335=	38.1252
T 339=	45.0353	T 341=	43.8755	T 342=	43.0141
T 346=	45.1432	T 347=	47.7156	T 348=	44.9831
T 353=	61.4913	T 354=	61.4913	T 355=	48.5924
T 361=	47.9092	T 362=	42.9060	T 372=	42.8063
T 376=	43.7896	T 378=	41.7003	T 379=	39.8033
T 383=	38.0665	T 384=	44.9656	T 385=	47.1583
T 389=	48.8325	T 390=	48.3396	T 391=	48.3662
T 395=	48.3337	T 396=	47.8701	T 397=	48.2930
T 403=	48.3401	T 404=	48.2244	T 405=	48.1023
T 413=	45.6531	T 414=	45.2962	T 415=	36.9328
T 424=	45.2955	T 425=	36.9321	T 431=	44.1021
T 435=	38.3229	T 436=	44.3720	T 437=	47.5814
T 442=	43.1087	T 443=	45.2946	T 444=	45.0302
T 448=	44.9186	T 449=	44.1122	T 451=	55.4833
T 455=	48.5832	T 456=	48.3479	T 457=	49.6245
T 472=	42.9154	T 473=	45.6499	T 474=	45.2933
T 479=	39.9512	T 480=	46.9247	T 481=	47.8505
T 485=	47.1183	T 486=	47.5832	T 487=	47.0657
T 491=	48.2811	T 492=	48.3891	T 493=	50.9626
T 497=	48.1399	T 498=	48.1398	T 501=	47.4015
T 505=	47.6639	T 506=	47.3228	T 511=	51.6485
T 515=	36.8825	T 521=	57.3318	T 522=	42.1670
T 531=	43.5629	T 532=	42.4362	T 533=	44.6010
T 537=	46.9443	T 538=	44.5560	T 539=	44.5293
T 544=	44.1467	T 545=	37.9785	T 546=	43.2578
T 551=	55.1242	T 552=	55.3791	T 553=	54.5581
T 557=	49.1329	T 558=	48.1094	T 561=	47.2960
T 574=	44.6313	T 575=	36.8781	T 576=	43.1142
T 581=	47.2057	T 582=	47.3976	T 583=	38.3670
T 587=	46.5446	T 588=	48.0340	T 589=	48.3325

T	145=	86.4906	T	146=	82.0719	T	147=	81.4304
T	151=	84.9461	T	152=	74.2476	T	153=	39.9080
T	162=	63.1032	T	163=	75.0577	T	164=	50.3093
T	168=	40.8010	T	169=	47.0184	T	170=	45.6893
T	174=	72.3135	T	175=	59.9397	T	176=	63.3832
T	184=	45.7736	T	185=	48.0957	T	186=	45.5561
T	190=	45.3650	T	191=	45.5730	T	192=	45.5569
T	196=	45.5135	T	197=	41.4398	T	198=	39.8136
T	202=	43.6041	T	203=	43.6965	T	204=	43.5865
T	212=	39.9434	T	213=	41.8281	T	214=	41.5724
T	223=	41.8273	T	224=	41.5715	T	225=	35.5335
T	234=	41.3620	T	235=	36.4979	T	236=	40.7772
T	241=	40.9612	T	242=	40.1387	T	243=	41.6753
T	247=	43.2253	T	248=	41.4623	T	249=	41.1497
T	254=	51.5851	T	255=	43.7966	T	256=	43.5405
T	262=	40.8450	T	272=	39.9402	T	273=	41.8252
T	278=	39.2121	T	279=	37.8027	T	280=	42.6570
T	284=	41.4169	T	285=	42.7614	T	286=	42.9429
T	290=	43.5221	T	291=	43.5072	T	292=	43.6901
T	296=	43.2703	T	297=	43.5327	T	298=	43.5327
T	304=	48.3797	T	305=	48.2564	T	306=	47.9066
T	314=	45.2466	T	315=	36.7336	T	321=	57.8390
T	325=	36.7329	T	331=	43.9110	T	332=	43.0211
T	336=	44.1817	T	337=	47.7050	T	338=	44.9725
T	343=	45.2880	T	344=	44.9911	T	345=	38.1183
T	349=	44.0802	T	351=	55.6374	T	352=	55.9281
T	356=	48.4329	T	357=	49.6325	T	358=	48.7619
T	373=	45.6445	T	374=	45.2437	T	375=	36.7293
T	380=	46.9909	T	381=	47.9949	T	382=	48.0535
T	386=	47.5835	T	387=	46.9224	T	388=	48.5257
T	392=	48.5471	T	393=	51.1209	T	394=	48.3337
T	398=	48.2930	T	401=	48.0340	T	402=	48.2500
T	406=	47.7591	T	411=	62.1257	T	412=	42.9193
T	421=	57.9013	T	422=	42.9186	T	423=	45.6524
T	432=	43.1466	T	433=	45.3294	T	434=	45.0649
T	438=	44.9184	T	439=	45.0999	T	441=	43.9069
T	445=	38.2850	T	446=	45.1023	T	447=	47.5817
T	452=	55.7702	T	453=	61.3333	T	454=	61.3333
T	458=	48.6703	T	461=	47.7417	T	462=	42.5420
T	475=	36.9285	T	476=	43.8449	T	478=	41.8239
T	482=	47.8981	T	483=	38.0485	T	484=	44.8984
T	488=	48.5164	T	489=	48.8242	T	490=	48.2476
T	494=	48.1797	T	495=	48.1796	T	496=	47.7261
T	502=	47.7793	T	503=	47.5972	T	504=	47.7638
T	512=	42.1677	T	513=	44.8621	T	514=	44.6340
T	523=	44.8613	T	524=	44.6333	T	525=	36.8818
T	534=	44.4320	T	535=	38.1776	T	536=	43.8323
T	541=	42.5388	T	542=	42.2372	T	543=	44.3157
T	547=	46.8198	T	548=	44.4314	T	549=	42.7539
T	554=	54.5581	T	555=	48.1058	T	556=	47.8011
T	562=	43.4670	T	572=	42.1643	T	573=	44.8586
T	578=	41.4584	T	579=	39.5599	T	580=	46.2619
T	584=	44.5582	T	585=	46.4902	T	586=	47.0297
T	590=	47.6642	T	591=	47.7295	T	592=	47.9179
T	593=	49.0022	T	594=	47.7051	T	595=	47.7049
T	596=	47.1001	T	597=	47.6521	T	598=	47.6519

BOUNDARY NODES

T	888=	32.2222	T	909=	26.6667	T

APPENDIX H

Complete Temperature Listing

Relay ON in Input Electronics

Increased PC Board Conductance in Input Electronics

TEMPERATURE IN DEGREES CELSIUS

```
TIMEN   = 0.                     EBALSC              = 0.              CSGMIN(
TSTEPII = 0.                     EBALNC(       0)    = 0.              CSGMAX(
                                 ITERCT              =        72       DMXTCC(
```

DIFFUSION
++N
ARITHMETI

T	1=	36.7498	T	2=	35.0186	T	3=	36.7689
T	7=	37.9676	T	8=	36.3561	T	9=	38.3859
T	13=	40.7962	T	14=	42.6288	T	15=	38.3495
T	19=	41.3932	T	20=	41.7561	T	21=	41.5430
T	25=	40.2571	T	26=	41.9673	T	27=	40.3568
T	31=	37.2334	T	32=	37.4083	T	33=	37.1586
T	37=	33.0785	T	38=	33.7042	T	39=	33.8484
T	43=	33.1480	T	44=	34.0564	T	45=	40.5691
T	54=	40.9053	T	55=	39.5827	T	56=	37.8176
T	72=	36.9119	T	73=	38.5920	T	74=	41.7527
T	78=	39.9459	T	79=	40.0366	T	80=	37.2982
T	84=	35.8891	T	85=	34.6184	T	86=	34.6630

```
      0) = 0.                    DRLXCC(       0)  = 0.
      0) = 0.                    ARLXCC(     174)  = 9.082703E-04
      0) = 0.                    AMXTCC(       0)  = 0.
```

NODES
ONE++
C NODES

T	4=	36.0565	T	5=	37.9506	T	6=	36.2928
T	10=	43.5831	T	11=	40.0357	T	12=	41.3031
T	16=	38.9735	T	17=	40.7367	T	18=	41.7805
T	22=	39.4847	T	23=	40.1196	T	24=	40.5187
T	28=	39.1213	T	29=	40.3555	T	30=	39.3859
T	34=	36.9625	T	35=	37.6425	T	36=	35.4571
T	40=	33.8544	T	41=	33.8605	T	42=	33.7385
T	51=	44.7367	T	52=	43.8082	T	53=	40.6399
T	57=	37.9321	T	58=	37.6815	T	71=	37.3429
T	75=	39.7447	T	76=	38.6880	T	77=	39.8834
T	81=	36.1096	T	82=	36.1710	T	83=	36.1478
T	87=	34.5470	T	88=	36.9266	T	141=	85.4505

DATE 03/24/76 TIME 12.58.07. MARTIN MARIETTA THERMAL ANALYZER SY

MODIFY PC BOARD G

T	142=	86.7012	T	143=	82.2612	T	144=	80.4280
T	148=	85.6919	T	149=	78.7719	T	150=	77.1764
T	154=	37.4426	T	155=	38.0625	T	156=	41.2526
T	165=	49.7341	T	166=	41.2700	T	167=	51.8640
T	171=	71.4322	T	172=	72.7820	T	173=	69.4303
T	181=	58.2364	T	182=	55.6798	T	183=	55.3565
T	187=	54.7174	T	188=	54.8189	T	189=	55.4159
T	193=	54.8553	T	194=	52.0638	T	195=	51.5035
T	199=	42.4255	T	200=	43.6415	T	201=	43.6298
T	205=	43.6367	T	206=	43.4247	T	211=	59.0957
T	215=	35.5937	T	221=	54.2936	T	222=	40.0291
T	231=	40.5968	T	232=	40.1375	T	233=	41.6531
T	237=	43.2956	T	238=	41.5186	T	239=	41.4493
T	244=	41.5871	T	245=	36.6527	T	246=	41.9925
T	251=	47.7001	T	252=	47.8805	T	253=	51.7119
T	257=	44.9382	T	258=	43.9074	T	261=	43.4822
T	274=	41.6706	T	275=	35.5897	T	276=	40.6867
T	281=	43.4961	T	282=	43.5514	T	283=	36.9539
T	287=	42.2746	T	288=	43.8755	T	289=	44.3160
T	293=	45.4156	T	294=	43.6841	T	295=	43.6841
T	301=	48.4375	T	302=	48.6542	T	303=	48.7493
T	311=	62.1608	T	312=	42.9707	T	313=	45.8483
T	322=	42.9700	T	323=	45.8476	T	324=	45.4436
T	333=	45.4813	T	334=	45.1820	T	335=	38.2478
T	339=	45.2314	T	341=	44.0519	T	342=	43.1783
T	346=	45.3416	T	347=	47.9566	T	348=	45.1960
T	353=	61.7419	T	354=	61.7419	T	355=	48.8165
T	361=	48.1633	T	362=	43.2226	T	372=	42.9678
T	376=	43.9620	T	378=	41.8551	T	379=	39.9355
T	383=	38.2318	T	384=	45.1801	T	385=	47.3816
T	389=	49.0474	T	390=	48.5719	T	391=	48.6008
T	395=	48.5830	T	396=	48.1142	T	397=	48.5418
T	403=	48.5573	T	404=	48.4416	T	405=	48.3200
T	413=	45.9406	T	414=	45.4872	T	415=	37.0674
T	424=	45.4965	T	425=	37.0667	T	431=	44.2759
T	435=	38.4649	T	436=	44.5448	T	437=	47.7924
T	442=	43.2746	T	443=	45.4825	T	444=	45.2206
T	448=	45.1235	T	449=	44.2947	T	451=	55.7009
T	455=	48.7865	T	456=	48.5533	T	457=	49.8241
T	472=	43.0781	T	473=	45.8379	T	474=	45.4844
T	479=	40.0954	T	480=	47.1231	T	481=	48.0644
T	485=	47.3195	T	486=	47.7880	T	487=	47.2690
T	491=	48.4967	T	492=	48.6072	T	493=	51.1798
T	497=	48.3558	T	498=	48.3558	T	501=	47.8262
T	505=	48.0894	T	506=	47.7447	T	511=	61.8774
T	515=	37.0486	T	521=	57.5647	T	522=	42.4157
T	531=	43.8342	T	532=	42.6493	T	533=	44.9125
T	537=	47.3505	T	538=	44.9070	T	539=	44.8452
T	544=	44.4497	T	545=	38.1630	T	546=	43.5526
T	551=	55.5499	T	552=	55.8068	T	553=	54.9858
T	557=	49.4794	T	558=	48.4955	T	561=	47.7321
T	574=	44.9453	T	575=	37.0445	T	576=	43.3854
T	581=	47.6224	T	582=	47.8259	T	583=	38.6397
T	587=	46.9142	T	588=	48.3975	T	589=	48.6794

T	145=	86.7012	T	146=	82.2612	T	147=	81.6642
T	151=	84.7563	T	152=	74.4293	T	153=	40.1777
T	162=	82.9015	T	163=	83.6734	T	164=	50.6626
T	168=	41.2700	T	169=	78.4894	T	170=	77.2458
T	174=	79.0594	T	175=	66.1943	T	176=	83.1815
T	184=	55.4256	T	185=	57.6755	T	186=	55.0799
T	190=	52.6633	T	191=	52.1424	T	192=	52.3749
T	196=	51.7687	T	197=	43.3581	T	198=	41.6327
T	202=	43.7306	T	203=	43.8234	T	204=	43.7130
T	212=	40.0299	T	213=	41.9330	T	214=	41.6735
T	223=	41.9322	T	224=	41.6727	T	225=	35.5929
T	234=	41.4608	T	235=	36.5629	T	236=	40.8656
T	241=	41.0595	T	242=	40.2272	T	243=	41.7794
T	247=	43.3488	T	248=	41.5718	T	249=	41.2469
T	254=	51.7119	T	255=	43.9088	T	256=	43.6597
T	262=	41.0000	T	272=	40.0267	T	273=	41.9302
T	278=	39.2929	T	279=	37.8736	T	280=	42.7712
T	284=	41.5262	T	285=	42.8755	T	286=	43.0576
T	290=	43.6407	T	291=	43.6264	T	292=	43.8171
T	296=	43.3943	T	297=	43.6586	T	298=	43.6587
T	304=	48.6297	T	305=	48.5061	T	306=	48.1544
T	314=	45.4443	T	315=	36.8440	T	321=	57.9927
T	325=	36.8433	T	331=	44.0839	T	332=	43.1845
T	336=	44.3546	T	337=	47.9458	T	338=	45.1853
T	343=	45.4844	T	344=	45.1851	T	345=	38.2416
T	349=	44.2566	T	351=	55.8870	T	352=	56.1792
T	356=	48.6666	T	357=	49.8476	T	358=	48.9940
T	373=	45.9456	T	374=	45.4411	T	375=	36.8397
T	380=	47.2224	T	381=	48.2407	T	382=	48.3043
T	386=	47.8102	T	387=	47.1396	T	388=	48.7495
T	392=	48.7984	T	393=	51.3717	T	394=	48.5830
T	398=	48.5418	T	401=	48.2502	T	402=	48.4675
T	406=	47.9761	T	411=	62.2729	T	412=	43.0812
T	421=	58.0573	T	422=	43.0805	T	423=	45.8399
T	432=	43.3106	T	433=	45.5142	T	434=	45.2524
T	438=	45.1218	T	439=	45.2874	T	441=	44.0895
T	445=	38.4299	T	446=	45.3047	T	447=	47.7941
T	452=	55.9881	T	453=	61.5501	T	454=	61.5501
T	458=	48.8744	T	461=	47.9615	T	462=	42.8011
T	475=	37.0632	T	476=	44.0118	T	478=	41.9874
T	482=	48.1157	T	483=	38.2451	T	484=	45.1038
T	488=	48.7199	T	489=	49.0241	T	490=	48.4522
T	494=	48.3962	T	495=	48.3960	T	496=	47.9385
T	502=	48.2054	T	503=	48.0253	T	504=	48.1885
T	512=	42.4164	T	513=	45.1827	T	514=	44.9482
T	523=	45.1820	T	524=	44.9475	T	525=	37.0479
T	534=	44.7387	T	535=	38.3642	T	536=	44.1037
T	541=	42.7903	T	542=	42.4882	T	543=	44.6235
T	547=	47.2239	T	548=	44.7804	T	549=	43.0144
T	554=	54.9858	T	555=	48.4685	T	556=	48.1903
T	562=	44.0567	T	572=	42.4133	T	573=	45.1800
T	578=	41.6998	T	579=	39.7618	T	580=	46.6300
T	584=	44.9138	T	585=	46.8587	T	586=	47.4065
T	590=	48.0512	T	591=	48.1193	T	592=	48.3466
T	593=	49.4302	T	594=	48.1274	T	595=	48.1274
T	596=	47.5139	T	597=	48.0734	T	598=	48.0734

BOUNDARY NODES

T	888=	32.2222	T	999=	26.6667	T

APPENDIX B

PRELIMINARY STRESS ANALYSIS OF THERMAL CONTROLLED POWER SUPPLY

BY
A. C. NEMES

MSFC STD POWER SUPPLY - STRESS ANALYSIS

1) FACTORS OF SAFETY
   a. 1.5 ULTIMATE
   b. 1.1 YIELD

2) LOAD FACTORS
   a. USE 1 G STRESS ANALYSIS
   b. THEN USE 100 g's FOR MARGIN OF SAFETY

3) MATERIALS - FOLLOWING ALUMINIUMS HAVE HIGH RESISTANCE TO STRESS CORROSION CRACKING
   a. O/R CHASSIS FROM 2.0 INCH STOCK
   b. MAIN FRAME CHASSIS FROM 1.5 INCH STOCK

6061-T651 $t = .50$ TO 2.00

$F_{tu} = 42$ KSI $F_{ty} = 35$ KSI (LT)

$F_{cy} = 35$ KSI (L) $F_{su} = 27$ KSI

$F_{BRu} = 67$ KSI $F_{BRy} = 50$ KSI

$E = 10.1 \times 10^6$ PSI

7075-T73 : PER EPS 10327

$F_{tu} = 67$ KSI $F_{ty} = 56$ KSI

$F_{cy} = 55$ KSI (L) & 58 KSI (LT)

$F_{BRu} = 105$ KSI $F_{BRy} = 84$ KSI

$E_c = 10.6 \times 10^6$ PSI

AL NEMES 3-29-76

2024-T62 $t = .500$ TO 3.00

$F_{tu} = 63$ KSI $F_{ty} = 50$ KSI

(NO OTHER MINIMUMS DEFINED IN MIL-HDBK 5B)

2219-T6 & T861

-T6 $t = .020$ TO 2.00

$F_{tu} = 54$ KSI $F_{ty} = 36$ KSI

$F_{cy} = 38$ KSI $F_{su} = 32$ KSI

$F_{bru} = 84$ KSI $F_{bry} = 63$ KSI

$E_c = 10.8 \times 10^6$

-T861 $t = 1.001$ TO 2.00

$F_{tu} = 62$ KSI $F_{ty} = 47$ KSI (L) & 46 KSI (LT)

$F_{cy} = 47$ KSI (L) & 49 KSI (LT)

$F_{su} = 36$ KSI $E_c = 10.8 \times 10^6$

$F_{bru} = 95$ KSI $F_{bry} = 77$ KSI

FOR MARGINS OF SAFETY CALCULATIONS IN THIS ANALYSIS, 6061-T651 WILL BE USED. ANY OF THE OTHER ALLOYS WILL ALLOW HIGHER LOAD CAPABILITIES OR REDUCED WEIGHT.

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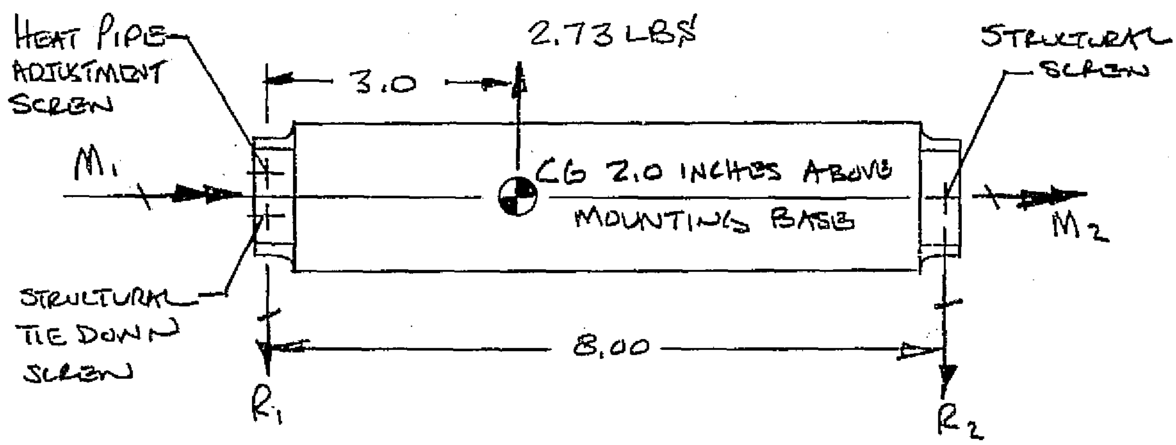
O/R CHASSIS IS HELD IN PLACE USING 140-160 KSI FASTENERS AND NON LOCKING HELI-COILS. EPOXY IS APPLIED TO HEAD OF SCREWS TO ELIMINATE POSSIBILITY OF BACK-OUT.

1g SIDE LOAD ON O/R CHASSIS

(CG POSITION ASSUMED DUE TO LOCATION OF INTERNAL COMPONENTS)



$R_1 = \frac{5.0}{8.0}(2.73) = 1.70$ LBS $\qquad R_2 = 1.03$ LBS

$M_1 = 2(2.73)\left(\frac{5}{8}\right) = 3.41$ IN-LB $\qquad M_2 = 2.05$ IN-LB

SINCE THE HEAT PIPE SCREW IS A VERY SOFT SPRING, (DUE TO RUBBER BEARING PAD ON HEAT PIPE PRESSURE CAM) ONE SCREW ON EACH SIDE MUST REACT THE LOADS

A. Nemes 4-1-76

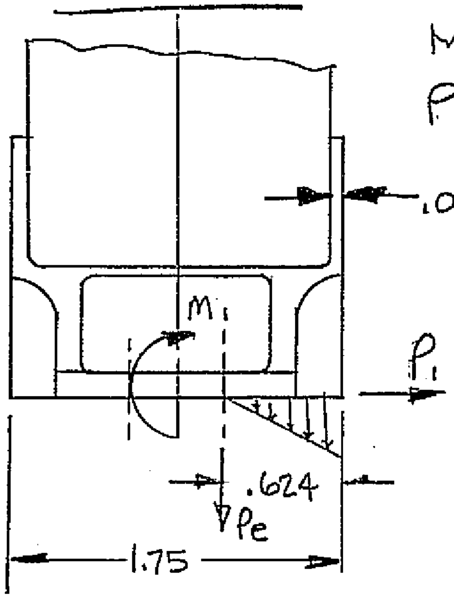
(1g. SIDE LOAD)

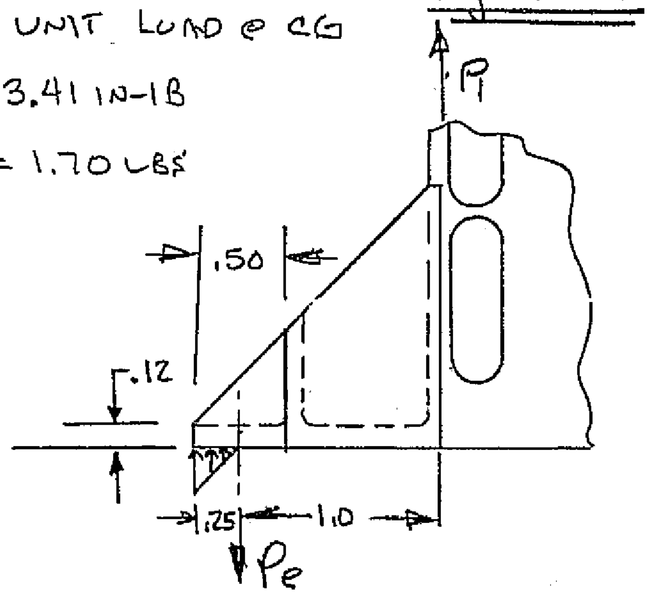
FOR UNIT LOAD @ CG

$M_1 = 3.41$ IN-LB

$P_1 = 1.70$ LBS

1 g UP LOAD





EXTERNAL BOLT LOAD

1g SIDE $P_e = \dfrac{3.41}{2/3(.624)}$ LBS

$P_e = 5.12$ LBS

1g UP $P_e = \dfrac{1.70(1.0 + 2/3(.25))}{2/3(.25)}$ LBS

$P_e = 11.90$ LBS

USING .190-32 FASTENER WITH TENSILE

AREA OF $0.02\ IN^2 \Rightarrow$ O.D. = .160 INCH

IF A-286 (NAS 1216 OR NAS 1218 TYPE)

$F_{tu} = 140$ KSI $\quad F_{ty} = 95$ KSI $\quad F_{su} = 91$ KSI

$P_u = 2,800$ LBS $\quad P_y = 1,900$ LBS $\quad P_{su} = 1,820$ LBS

PRELOAD FASTENER TO APPROXIMATELY 70% YIELD

$\sigma_{PRE} = .6(95 KSI) = 57,000$ PSI $\Rightarrow$ USE 60 KSI

$P_i = 60,000(.02) = 1,200$ LBS

$T = .2(1200)(.160) = 38.4$ IN-LB

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USE 38 ± 3 IN-LB ON STRUCTURAL SCREWS'
NEED TO WORK STIFFNESS OF BOLT AND CLAMPED JOINT TO FIND TOTAL INTERNAL BOLT LOAD UNDER EXTERNAL JOINT LOADING.

BOLT STIFFNESS   EFFECTIVE BOLT LENGTH $\approx L_b = .30$ IN.

$$K_b = \frac{A_b E_b}{L_b} = \frac{(.02)(29 \times 10^6)}{(.30)} = 1.93 \times 10^6 \frac{LB}{IN}$$

JOINT STIFFNESS

$$A_c = .7854\left(D_e^2 - d^2\right)$$

$$K_c = \frac{A_c E_c}{L_c} \quad \text{where, } D_e = \phi_{\text{BOLT HEAD}} + \frac{L_c}{2}$$

L_c = FLANGE THICKNESS

$D_e = .312 + \frac{.090}{2} = .375$ IN d = HOLE DIAMETER

$$K_c = \frac{(.7854(.375^2 - .217^2)(10.1 \times 10^6)}{.090} = 8.24 \times 10^6 \frac{Lb}{IN}$$

EXTERNAL LOAD TO OPEN JOINT ~

$$P_i\left(\frac{K_c + K_b}{K_c}\right) = 1200\left(\frac{8.24 + 1.93}{8.24}\right) = 1480 \text{ LBS'}$$

TOTAL BOLT LOAD IS THEN (@ 100g's UP LOAD)

$$P_{t_b} = P_e\left(\frac{K_b}{K_b + K_c}\right) + P_i = 1190\left(\frac{1.93}{8.24 + 1.93}\right) + 1200 \text{ LBS'}$$

$P_{t_b} = 1426$ LBS (TENSION)

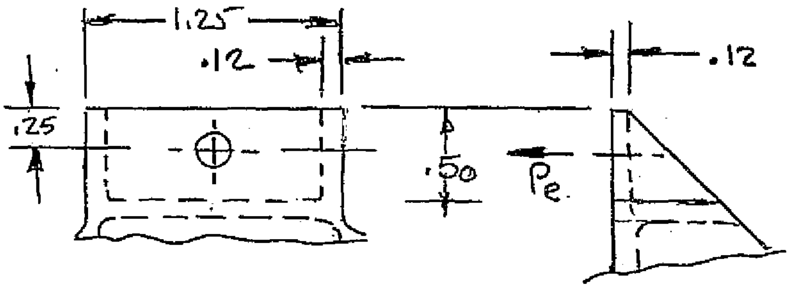
MARGIN OF SAFETY

$$MS' = \frac{2800}{1.5(1426)} - 1 \qquad \boxed{MS' = +.31}$$

BOLT TENSION

AL NAMES 4-1-76

USE BATHTUB FITTING ANALYSIS — CONSERVATIVELY MOVE LOAD TO CENTER OF FITTING ~



END PAD BENDING (LOCKHEED STRESS MEMO 88a)

$$\left.\begin{aligned} \frac{r_2}{a} &= \frac{.217}{2(.56)} = .194 \\ \frac{b}{a} &= \frac{1.12}{.56} = 2.0 \end{aligned}\right\} \Rightarrow K_3 = .72 \quad \text{FROM FIG 8}$$

$$\sigma = \frac{P_e(2d - t_b)K_3}{t_e^2\, a} = \frac{1190(2(.37) - .12)(.72)}{(.12)^2(.56)} \text{ PSI}$$

σ_b = 658.775 PSI @ 1g SIDE LOAD

FOR 100g LOADING σ = 65,877,50 PSI & WILL NEED THICKER END PAD

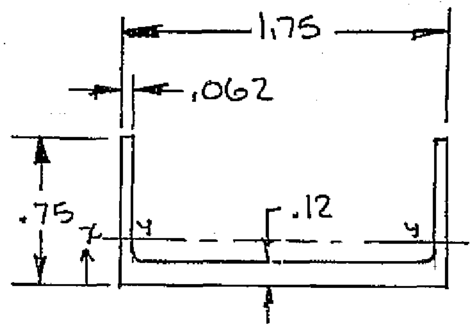
USING 6061-T6 F_{tu} = 42,000 PSI, PLASTIC FACTOR K=1.45, FACTOR OF SAFETY = 1.50

$$t_e^2 = \frac{(1,190)(2(.37) - .12).72}{\left(\frac{42,000 \times 1.45}{1.5}\right)(.56)} \Rightarrow \boxed{t_e = .154 \text{ INCH}}$$

END PAD THICKNESS REQD. (PLASTIC BENDING)

AL NEMES 4-2-76

BENDING IN $t = .062$ WALLS BEHIND INITIAL BATH TUB —



	A	x	AX	Ax^2	I_{oy}
BASE	.145	.06	.0117	.000702	.000234
FLG	.093	.375	.0348	.01305	.004359
	.288		.0465	.01375	.004593

$$\bar{x} = \frac{.0465}{.288} = .161 \text{ IN}$$

$$I_{yy} = .00459 + .01375 - .161 \times .0465 = .01086 \text{ IN}^4$$

FOR 100 g SIDE LOAD —

$$M = 1190(.50) = 595 \text{ IN-LB}$$

STRESS IN TENSION FLANGE ~

$$\sigma = \frac{Mc}{I} = \frac{(595)(.75-.161)}{.01086} = 32{,}270 \text{ PSI (LIMIT)}$$

USING PLASTIC FACTOR $k = 1.45$ —

$$MS' = \frac{42{,}000(1.45)}{32{,}270(1.5)} - 1 \qquad MS' = +.26$$

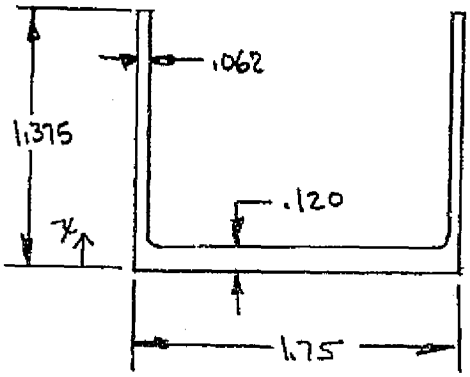
COMPRESSION IN BASE

$$\sigma = \frac{(595)(.161)}{.01086} = 8{,}820 \text{ PSI (LIMIT)}$$

$$MS' = \frac{35{,}000}{8820(1.5)} - 1 \qquad MS' = +1.65$$

AL NAMES 4-2-76

BENDING BACK AT VERTICAL WALL IN $t = .062$ FLANGES ~



	A	$\bar{x}$	AX	AX^2	I_{oy}
BASE	.195	.06	.0117	.000702	.000234
FLG	.170	.6875	.1168	.0803	.026863
	.365		.1285	.081002	.027097

$$\bar{x} = \frac{.1285}{.365} = .352$$

$$I_{yy} = .02709 + .08100 - .352(.1285) \ \text{IN}^4$$

$$I_{yy} = .06286 \ \text{IN}^4$$

TENSION STRESS IN FLANGE ~ @ 100 g's

$$M = 1190\,(1.00) = 1190 \ \text{IN-LB}$$

$$\sigma = \frac{Mc}{I} = \frac{1190\,(1.375 - .352)}{.06286} = 19{,}370 \ \text{PSI (LIMIT)}$$

$$M.S. = \frac{42{,}000}{(1.5)(19{,}370)} - 1 \qquad \boxed{M.S. = +.44}$$

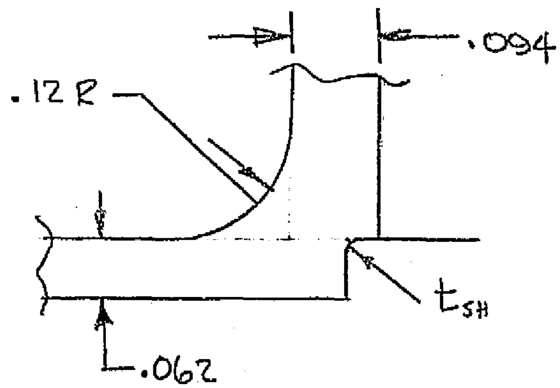
TENSION STRESS

CALCULATE SHEAR STRESS BETWEEN $t = .062$ FLANGES AND 1.625 WIDE BOX SECTION DUE TO OVERLAP GUSSET ATTACH ~

RUNNING SHEAR LOAD @ TOP (@ 100 g's

$$w = 19{,}370 \ \frac{\text{LB}}{\text{IN}^2} \times .062 \ \text{INCH} = 1200 \ \text{LB/IN (LIMIT)}$$

AL NOMES



$t_{SH} \approx .100$ INCH

SHEAR STRESS $\tau \approx \frac{1200}{.100} = 12,000$ PSI (Limit)

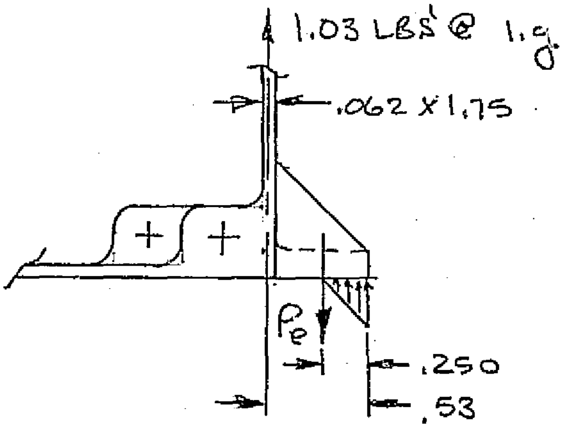
$M.S.' = \frac{27,000}{(1.5)(12000)} - 1$

$\boxed{M.S.' = +.50}$
SHEAR STRESS

AL NEMES

SIDE 2 FITTING — USE SAME END PAD THICKNESS OF $t = .154$ INCH.

CHECK BONDING UP WALL (VERY CONSERVATIVE)



$$P_e = \frac{1.03(.53)}{\frac{2}{3}(.25)} \text{ LBS'}$$

$P_e = 6.18$ LBS'

$L = .30$ INCH

@ 100 g's $P_e = 618.0$ LBS'

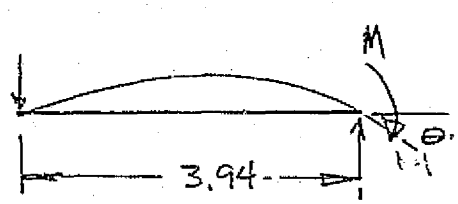
BOLT ELONGATION

$$\delta = \frac{P\ell}{AE} = \frac{(618)(.3)}{(.02)(29 \times 10^6)} = 3.197 \times 10^{-4} \text{ INCH}$$

JOINT ROTATION

$$\theta = \tan^{-1} \frac{3.197 \times 10^{-4}}{.250} = 7.326 \times 10^{-2} \text{ degrees} = 1.2786 \times 10^{-3} \text{ RADIANS}$$

IDEALIZE SIDE MEMBER AS SUPPORTED BEAM WITH INDUCED MOMENT RESULTING IN ROTATION θ



$$M = \frac{3EI\theta}{\ell}$$

$$M = \frac{3 \times 10.1 \times 10^6 \left(\frac{1}{12}(1.75 \times .062^3)\right)(.0012786)}{3.94}$$

$M = .342$ IN-LB

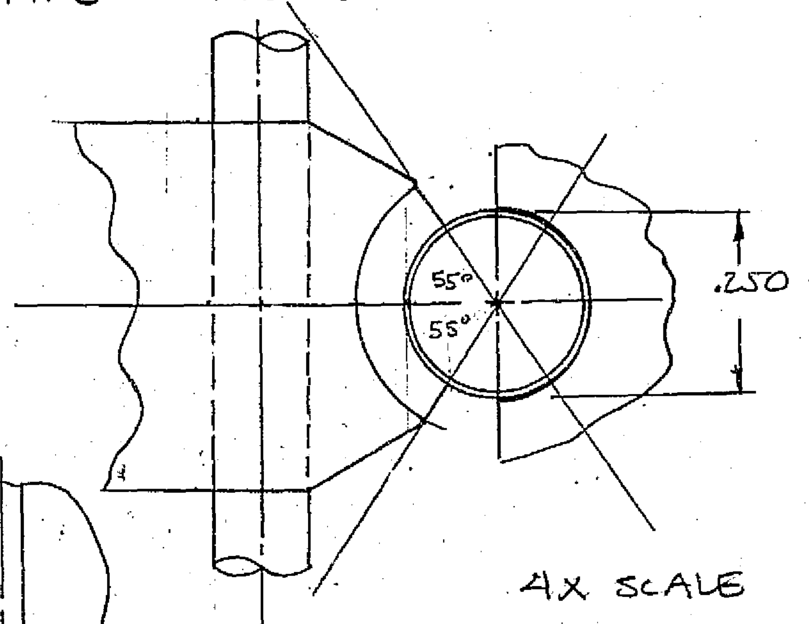
AL Nomos 4-2-76

BENDING STRESS IS THEN

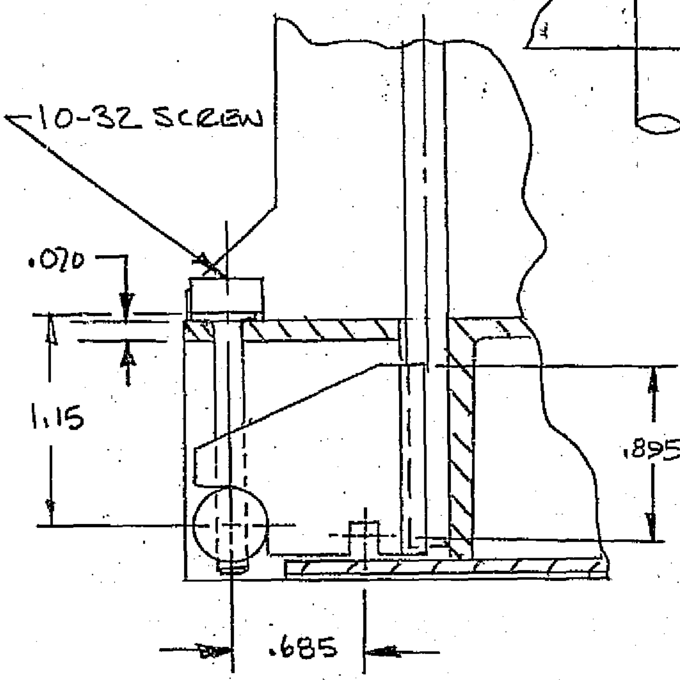
$$\sigma = \frac{6M}{bt^2} = \frac{6(.342)}{(1.15)(.062)^2} = 305 \text{ PSI (LIMIT)}$$ NO PROBLEM

@ 100 g's

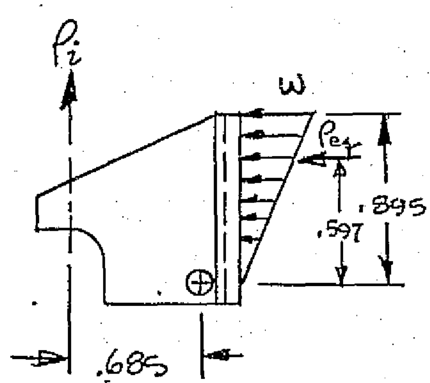
CHECK HEAT PIPE INSTALLATION AND LOWER CLAMPING SYSTEM ~



4X SCALE



FULL SCALE



TUBE PRELOAD DIAGRAM

AL NOMES 4-2-76

LIMIT 10-32 SCREW PRELOAD TO MAINTAIN ALLOWABLE WALL BENDING STRESS IN HEAT SINK WALL.

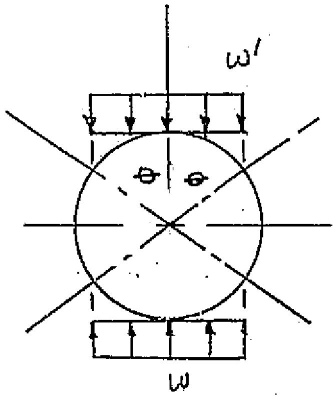
HEAT SINK - STAINLESS, $t_{WALL} = .030$ INCH

- ASSUME ANNEALED 300 SS

$F_{tu} = 75$ KSI $\quad F_{ty} = 30$ KSI $\quad F_{cy} = 27$ KSI

- USE FS = 2.0 ON YIELD

LOADING INTO TUBE - ASSUME RING



$\theta = 55° = .95993$ RADIANS

$R = .250$ IN

$$M_{MAX} = w'R^2\left(.3183\left(\frac{\theta}{2} + \theta \sin^2\theta + \frac{3}{2}\sin\theta\cos\theta\right) - \frac{1}{2}\sin^2\theta\right)$$

$$M_{MAX} = w'(.25)^2\left(.3183\left(\frac{.95993}{2} + .95993 \sin^2 55 + \frac{3}{2}\sin 55 \cos 55\right) - \frac{1}{2}\sin^2 55\right)$$

$$M_{MAX} = \frac{w'(.24662)}{16} = 0.01541\, w' \text{ IN-lb}$$

$$\sigma = \frac{6M}{bt^2} \qquad \text{ASSUME } b = .895 \text{ INCH}$$

$$\frac{27{,}000}{2} = \frac{6M}{(.895)(.03)^2} \Rightarrow M = 1.812 \text{ IN-LB}$$

AL NEMES 4-2-76

$$w' = \frac{1.812}{.01541} = .118 \frac{LB}{IN} \qquad P'_{eq} = .118 \frac{LB'}{IN} \times .895 IN = .106 LBS$$

CALCULATE EQUIVALENT BEARING PRESSURE ON TUBE BY CONVERTING TRIANGULAR LOADING TO P_{eq} & THEN DIVIDING BY BEARING AREA

$$P_{eq} = \frac{w}{2}(.895) \quad \& \quad \sigma_{BR} = \frac{P_{eq}}{2R\sin\theta(.895)} \text{ PSI}$$

$$w = \frac{2(106)}{.895} = 236 \frac{LB}{IN}$$

$$\sigma_{BR} = \frac{106}{2(.125)(\sin 55)(.895)} = 290 \text{ PSI}$$

RUBBER ANALYSIS — { REF: HANDBOOK OF MOLDED & EXTRUDED RUBBER BY GOODYEAR }

$$\text{SHAPE FACTOR} = \frac{\text{LOAD AREA}}{\text{FREE AREA}}$$

$$SF = \frac{110/360(.125\pi)(.895)}{(.895 + \frac{110}{360}.125\pi)(2)(.106)} = \frac{.215}{.136} \approx 1.60$$

FOR 50 DUROMETER & 20% COMPRESSION (Pg 71 FIG 5-12)

$P_c = 410$ PSI (TOO MUCH FOR TUBE)

BOOK RECOMMENDS ONLY 12% COMPRESSION

$P_c = 200$ PSI, WITHIN TUBE ALLOWABLE

FOR $P_c = 300$ PSI, 15% COMPRESSION RESULTS

AL NEMES 4-2-76

WHAT TORQUE FOR 10-32 SCREW WILL RESULT IN DESIRED COMPRESSION ~ 300 PSI

FOR $P_{eq} = 106 \times \frac{300}{290} = 110$ LBS

$P_i = \frac{.597(110)}{.685} = 96$ LBS

TORQUE REQUIRED TO PRODUCE THIS PRELOAD ~

$T = KDP$ $\quad K \approx .20$
$\quad D = .160$ INCH

$T = (.2)(.160)(96) = 3.00$ INCH LBS

USE: $T = 48$ IN-OZ $\pm$ 4 IN-OZ

IF USE 70 DUROMETER RUBBER @ 300 PSI WILL GET INITIAL COMPRESSION OF 8-9%

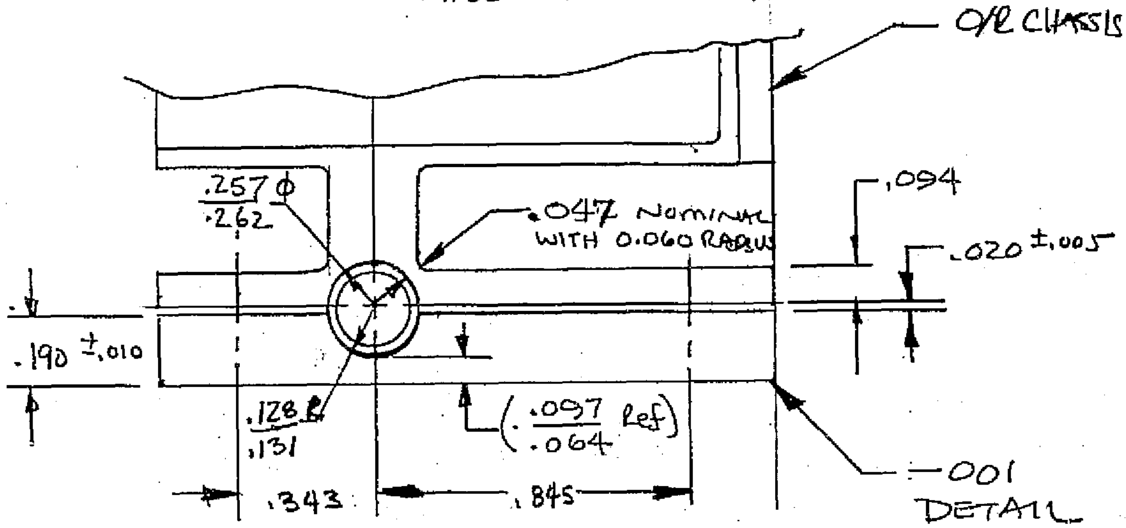
AL NEMES 4-2-76

HEAT PIPE CLAMPING INSTALLATION

SS TUBE $\phi = .250 {}^{+.000}_{-.005}$ INCH

$t_{WALL} = .030$ INCH

.022

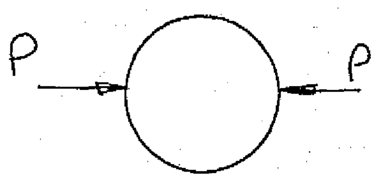


INITIAL LOADING ON HEAT PIPE WILL BE OPPOSIDE (180°) POINT LOADING. AS PIPE YIELDS THE LOAD WILL SPREAD AND GAP WILL CLOSE. CALCULATE LOAD TO DEFLECT PIPE THE NOMINAL INTERFERENCE.

$$\delta_{NOM} = \phi_{HEAT\ PIPE} - \phi_{HOLE}$$

$$= .250 - \left(\frac{.257 + .262}{2}\right) - \left[\left(\frac{.128 + .131}{2}\right) - .020\right] \text{ IN}$$

$$\delta_{NOM} = .250 - .12975 - .1095 = .010 \text{ INCH}$$



$M = .3183\, PR$ IN-LB

$$\delta_x = \frac{.149\, PR^3}{EI}$$

AL NEMES 4-5-76

LOAD TO COMPRESS TUBE 0.010 INCHES

$$P = \frac{EI\delta_x}{.149 R^3} = \frac{(29\times10^6)\frac{1}{12}(1.00)(.030)^3(.010)}{(.149)(.125)^3} \ \frac{LB}{INCH}$$

$$P = 2242 \ LB/IN$$

$$M = .3183(2242)(.125) = 89.20 \ IN\text{-}LB$$

$$\sigma = \frac{6M}{t^2} = \frac{6(89.20)}{(.03)^2} = 595{,}000 \ PSI$$

THE TUBE YIELDED LONG BEFORE THE ABOVE COMPRESSIVE LOAD WAS REACHED. FROM MIL-HDBK 5B THE MATERIAL STRESS-STRAIN CURVE IS FLAT AT $\sigma_y = 33$ KSI & MATL STARTS YIELDING AS LOW AS 15 KSI IN TENSION (TRANSVERSE DIRECTION)

LOAD TO PRODUCE INITIAL YIELDING

$$\sigma = \frac{6M}{t^2} = \frac{6(.3183)(P)(R)}{t^2} \Rightarrow P = \frac{\sigma t^2}{6(.3183)R} \ \frac{Lb}{IN}$$

$$P_{15KSI} = \frac{(15{,}000)(.03)^2}{6(.3183)(.125)} = 56.55 \ LB/IN$$

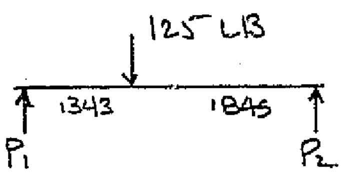
LOAD TO PRODUCE $\sigma_y = 33$ KSI

$$P_{33KSI} = \frac{33}{15}(56.55) = 125 \ LB/IN$$

AL NEMES 4-5-76

THIS LOAD OF $P = 125$ LB/IN SHOULD SUSTAIN YIELDING UNTIL GAP CLOSES. NOTE THIS NEGLECTS ANY DEFORMATION IN THE CLAMPING PIECES (-001 DETAIL AND O/R CHASSIS).

FOR STRESS IN O/R CHASSIS & -001 DETAIL - IDEALIZE AS SS BEAMS



$$P_1 = \frac{.845}{1.188}(125) = 88.9 \text{ LBS}$$

$$P_2 = 36.1 \text{ LBS}$$

$$M = 88.9(.343) = 30.49 \text{ IN-LB/IN}$$

STRESS IN -001 DETAIL $t_{nom} = \frac{.097+.064}{2} = .0805$ IN

$$\sigma = \frac{6M}{t^2} = \frac{6(30.49)}{(.0805)^2} = 28,230 \text{ PSI} \quad \left(\begin{matrix}\text{TUBE}\\ \text{YIELDING}\end{matrix}\right)$$

$$FS = \frac{35,000}{28,230} = 1.24$$

STRESS IN O/R CHASSIS

$$\sigma = \frac{6(30.49)}{(.047)^2} = 82,800 \text{ PSI} \quad \left(\begin{matrix}\text{TUBE}\\ \text{YIELDING}\end{matrix}\right)$$

THIS PART WILL YIELD BEFORE THE $P = 125$ POUND LOAD IS MAINTAINED

AL NOMES 4-5-76

INCREASE THICKNESS OF WEB BEHIND HEAT PIPE FROM .240 TO .320 INCH. THIS GIVES MIN THROAT THICKNESS OF 0.080 INCH (WAS 0.047 INCH)

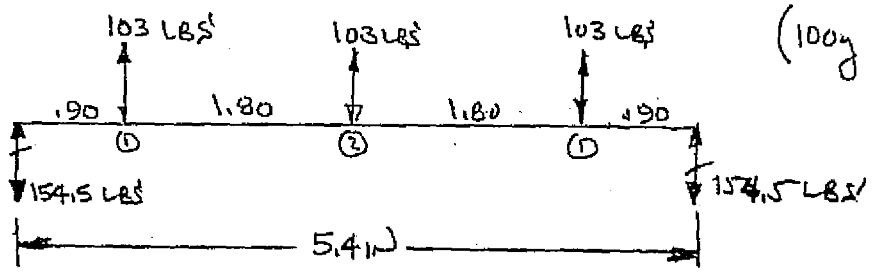
$$\sigma = \frac{6\,(30.49)}{(.08)^2} = 28{,}580 \text{ PSI} \quad \left(\begin{array}{c}\text{TUBE}\\ \text{YIELDING}\end{array}\right)$$

$$FS = \frac{35{,}000}{28{,}580} = 1.22$$

AL NEMES 4-5-76

CHECK BENDING STRESS IN BASE CHASSIS ON SIDE WITH TWO 10-32 SCREWS HOLDING BOX IN POSITION. USE SIMPLY SUPPORTED ASSUMPTION

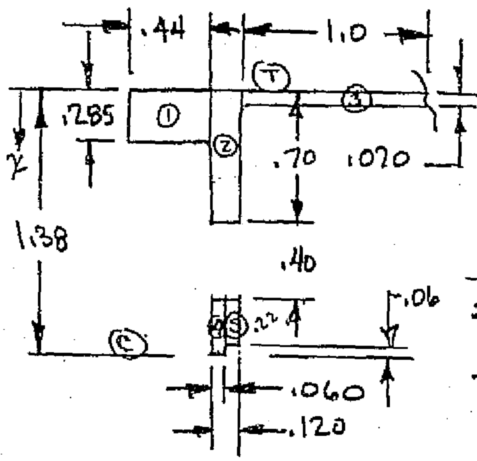
(100g LOADING)



$M_1 = 154.5(.9) = 139.05$ IN-LB

$M_2 = 154.5(2.7) - 103(1.80) = 231.75$ IN-LB

SECTION OF BEAM



	A	x	Ax	Ax²	Ioy
①	.1254	.1425	.01787	.002546	.0008488
②	.084	.350	.0294	.01029	.00343
③	.070	.035	.00245	.0000857	.0000286
④	.0168	1.24	.020832	.025831	.00010976
⑤	.0176	1.21	.021296	.02576816	.00007098
Σ	.3138		.09185	.064521	.004488

$$\bar{x} = \frac{.09185}{.3138} = .2927 \text{ IN}$$

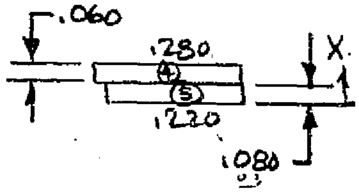
$$I_{y_0} = .004488 + .064521 - .2927 \times (.09185) = .04212 \text{ IN}^4$$

STRESS IN COMPRESSION FLANGE

$$\sigma = \frac{Mc}{I} = \frac{231.75(1.38 - .2927)}{.04212} = 5980 \text{ PSI (COMP)}$$

AL NOMOS 4-5-76

COMPRESSION STABILITY OF PLATE BELOW CONNECTOR (ELEMENTS 4 & 5 IN ABOVE SECTION)



	A	X	AX	AX²	I_{oy}
4	.0168	.110	.001848	.00020328	
5	.0176	.040	.000704	.00002816	
	.0344		.002552	.00023144	

$$\bar{x} = \frac{.002552}{.0344} = .0742 \text{ INCH}$$

$$I_{yy} = .00023144 - .0742(.002552) = .000421 \text{ IN}^4$$

$$\rho = \sqrt{\frac{I}{A}} = \sqrt{\frac{.000421}{.0344}} = .1106 \text{ IN}$$

IDEALIZE AS PINNED END COLUMN $L = 2.75 \text{ IN}$
$c = 1$

$$\sigma_{CR} = \frac{\pi^2 E_t}{\left(\frac{L}{\sqrt{c}\rho}\right)^2} = \frac{\pi^2 (10.1 \times 10^6)}{\left(\frac{2.75}{.1106}\right)^2} = 1.59 \times 10^5 \text{ PSI} > F_{cy}$$

NEED TO USE PLASTIC REDUCTION & E_t

$$\frac{L'}{\rho} = \frac{2.75}{.1106} \approx 25$$

$$\frac{F_{cy}}{E} = \frac{35000}{10.1 \times 10^6} = 3.46 \times 10^{-3}$$

USING NON-DIMENSIONAL COLUMN CURVE

$$\frac{\sigma_{CR}}{E} = 3.25 \times 10^{-3} \Rightarrow \sigma_{CR} = 32{,}825 \text{ PSI}$$

USING METHOD IN BRUHN PG 2.7 FIG C2.17

6061-T6 $n = 31$ $\sigma_{0.7} = 35 \text{ KSI}$

AL NOMES 4-5-76

$$\beta = \frac{1}{\pi}\sqrt{\frac{\sigma_{0.7}}{E_C}}\left(\frac{L'}{\rho}\right) = \frac{1}{\pi}\sqrt{\frac{35\ KSI}{10.1\times10^6}}\left(\frac{3.75''}{.1106}\right) = .466$$

$$\sigma_{CR} = 35{,}000\,(.93) = 32{,}550\ PSI$$

$$FS = \frac{32{,}550}{5{,}980} = 5.4$$

CHECK CHASSIS FLAT PLATE EQUIPMENT MOUNTING SURFACE FOR BENDING UNDER NORMAL PRESSURE.

ASSUME 7" x 9" FLAT PLATE. $t = .070$ INCH

ASSUME SIMPLY SUPPORTED PLATE

$$\frac{a}{b} = \frac{9.0}{7.0} \approx 1.30 \qquad \alpha = .0693 \quad \beta = .4146$$

$$\sigma = \frac{\beta w b^2}{t^2} \qquad \delta = \frac{\alpha w b^4}{E t^3}$$

$$\text{LIMIT } \delta = \frac{t}{2} = \frac{.070}{2} = .035\ \text{INCH}$$

$$w = \frac{E t^3 \delta}{\alpha b^4} = \frac{(10.1\times10^6)(.07)^3(.035)}{(.0693)(7)^4} = .728\ PSI$$

$$\sigma = \frac{.4146(.728)(7)^2}{(.07)^2} = 3{,}020\ PSI\ (\text{LIMIT})$$

TOTAL CHASSIS WEIGHT IS APPROX 4.43 LBS

$$\text{COMPONENTS} = 4.43^{LBS} - \left(\frac{811\,\text{grams (CHASSIS)} + 205\,\text{grams (COVER)}}{454\,\frac{\text{grams}}{\text{LB}}}\right) = 2.19\ \text{LBS}$$

AL NEMES 4-6-76

SMEAR COMPONENTS OVER TOTAL AREA

$$\omega' = \frac{2.19\ LBS'}{9 \times 7\ IN^2} = .034\ \frac{LB}{IN^2}$$

ALLOWABLE G LOADING

$$G = \frac{\omega}{\omega'} = \frac{.728}{.034} = 21.\ g's \leftarrow \text{LOW}$$

IF USE $t = .090$ INCH

$$S_{ALL} = \frac{.090}{2} = .045 \text{ INCH}$$

$$\omega = \frac{(10.1 \times 10^6)(.09)^3(.045)}{(.0693)(7)^4} = 1.99 \text{ PSI}$$

$$G = \frac{1.99}{.034} = 59\ g's \leftarrow \text{LOW}$$

WHAT THICKNESS NEEDED FOR 100 g's

$$w' = 3.4 \text{ PSI}$$

$$\frac{t}{2} = \frac{\alpha w b^4}{E t^3} \Rightarrow t^4 = \frac{2\alpha w b^4}{E}$$

$$t = \sqrt[4]{\frac{2(.0693)(3.4)}{(10.1 \times 10^6)}}\ (7.0) = .102 \text{ INCH}$$

USE $\boxed{t_{NOM} = .100 \text{ INCH}} \leftarrow$

ΔWT INCREASE $= .03 \times .1 \times 9 \times 7 = .189$ LBS $= 86$ GRAMS

Al Nemes 4-6-76

ESTIMATE PLATE FREQUENCIES :

REF NASA SP 160 ; CHAPTER 4 TP 4.1 Pg 43

ASSUME ALL EDGES SIMPLY SUPPORTED - UNIFORM LOAD

$$f = \sqrt{\frac{D}{\rho}} \left[\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 \right] \qquad D = \frac{Et^3}{12(1-\nu^2)} \qquad \rho = \frac{w}{386}$$

CHASSIS $t = .100$ INCH $a = 9$ IN $b = 7$ IN

$$\rho = \frac{.10 + \frac{2.19}{9 \times 7}}{386} = \frac{.135}{386} \quad @ \ 1g$$

$$f = \sqrt{\frac{\overset{(1626)}{\frac{10.1 \times 10^6 (.1)^3}{12(1-.3^2)}}}{\frac{.135}{386}}} \left[\overset{.3233}{\left(\frac{\pi}{9}\right)^2 + \left(\frac{\pi}{7}\right)^2} \right] = 526 \text{ HZ}$$

CHASSIS BOTTOM PLATE $a = 9$ $b = 7$ $t = .06$ $\rho = \frac{.1}{386}$

$$f = \sqrt{\frac{\frac{10.1 \times 10^6 (.06)^3}{12(.91)}}{\frac{.1}{386}}} \left[\left(\frac{\pi}{9}\right)^2 + \left(\frac{\pi}{7}\right)^2 \right] = 284 \text{ HZ}$$

O/R CHASSIS COVER $a = 6.12$ $b = 3.62$ $t = .060$ $\rho = \frac{.1}{386}$

$$f = \sqrt{\frac{\overset{873}{\frac{10.1 \times 10^6 (.06)^3}{12(.91)}}}{\frac{.1}{386}}} \left[\left(\frac{\pi}{6.12}\right)^2 + \left(\frac{\pi}{3.62}\right)^2 \right] = 892 \text{ HZ}$$

Al Nomes 4-6-76

USING METHOD OF TABLE 7.9, SHOCK & VIBRATION HANDBOOK –

$$f_n = \frac{23.6}{2\pi}\left[\frac{Dg}{\gamma t a^4}\right]^{1/2} \qquad D = \frac{Et^3}{12(1-\nu^2)}$$

$g = 386$ IN/SEC^2

γ = WEIGHT DENSITY

CHASSIS EQUIPMENT PLATE –

$t = .100$ IN $\qquad a = 7.0 \qquad b = 9.0$

$$w = \left(\frac{.10 \times 7 \times 9 \times .1 + .219}{.1 \times 9 \times 7}\frac{}{\text{IN}^3}\right)\text{LB} = .448\ \frac{\text{LB}}{\text{IN}^3}$$

$$D = \left[\frac{(10.1\times10^6)(.1)^3}{12(.91)}\right] = 924.9 \quad \text{IN-LB}$$

$$f_n = \frac{23.6}{2\pi}\left[\frac{924.9 \times 386}{.448 \times .1 \times (7)^4}\right]^{1/2} = 216.4 \text{ HZ}$$

BOTTOM CHASSIS COVER PLATE

$t = .060 \qquad \gamma = .10$ LB/IN^3

$$D = \frac{(10.1\times10^6)(.06)^3}{12(1-\nu^2)} = 199.8$$

$$f_n = \frac{23.6}{2\pi}\left[\frac{199.8 \times 386}{.1 \times .06 \times 7^4}\right]^{\frac{1}{2}} = 274.8 \text{ HZ}$$

O/R SIDE COVER PLATE $\qquad t = .060 \quad a = 3.62$ IN

$$f_n = \frac{23.6}{2\pi}\left[\frac{199.8 \times 386}{.1 \times .06 \times 3.62^4}\right]^{\frac{1}{2}} = 1028 \text{ HZ}$$

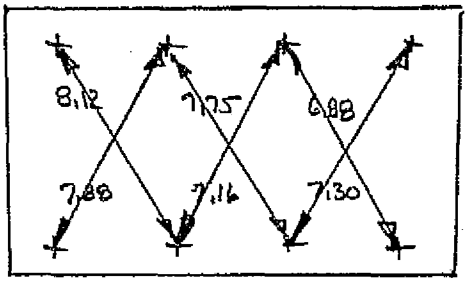
AL NOMES 4-6-76

USING MMC METHOD ON t=.060 COVERS

$$f_n \approx 3\times10^4 \sqrt{\frac{t^3}{\omega}\left(\frac{1}{l_1^4}+\frac{1}{l_2^4}\right)}$$

t = thickness
w = normal pressure load
l_1 & l_2 = distance between fasteners

CHASSIS BOTTOM COVER



$t = .060$

$\omega = .1 \times .06 = .006 \frac{lb}{in^2}$

$l_1 = 8.12$ IN

$l_2 = 7.88$ IN

$$f_n = 3\times10^4 \sqrt{\frac{(.06)^3}{(.006)}\left[\frac{1}{8.12^4}+\frac{1}{7.88^4}\right]} = 126 \text{ HZ}$$

O/R SIDE COVER

$l_1 = 5.6$ IN $l_2 = 5.6$ IN $\quad t = .06$

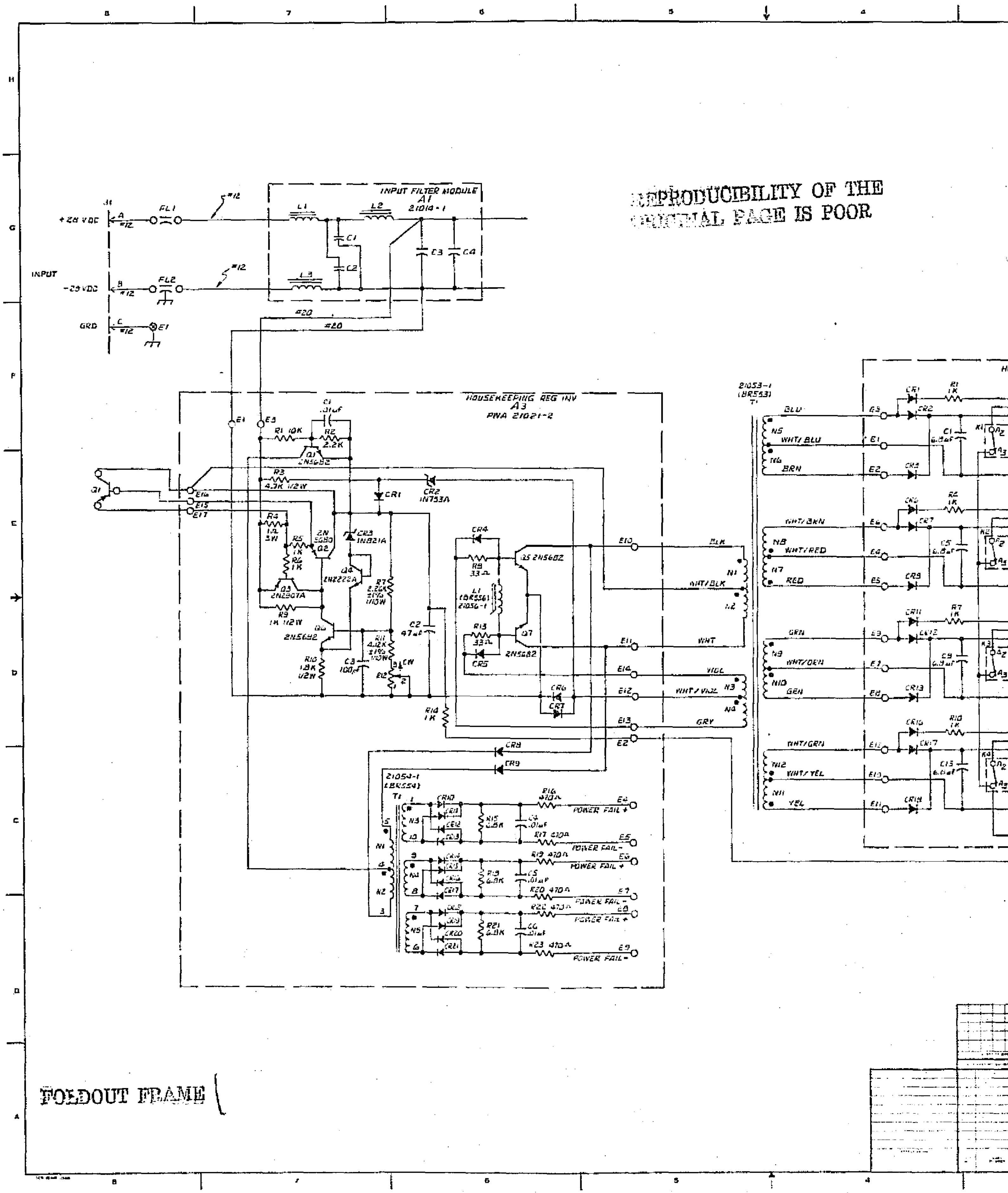
$$f_n = 3\times10^4 \sqrt{\frac{(.06)^3}{(.006)}\left[\frac{2}{5.6^4}\right]} = 256.7 \text{ Hz}$$

∴ THE ABOVE FREQUENCIES SHOULD BE USED TO CALCULATE LOADS WHEN THE g^2/HZ VS FREQUENCY CURVES ARE DEFINED FOR POWER SUPPLY.

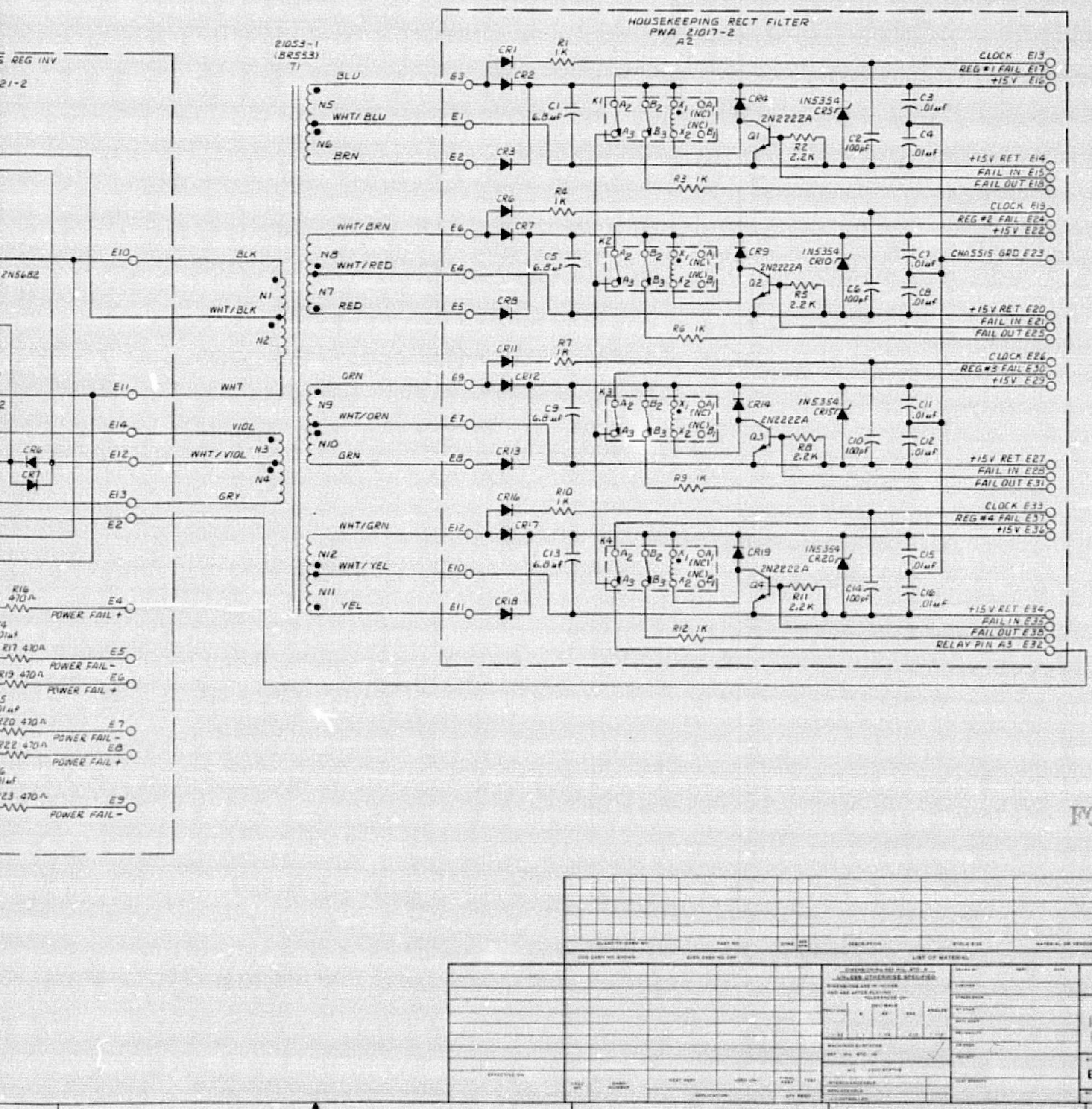
AL NOMUS 4-6-76

APPENDIX C

POWER SUPPLY PACKAGING AND PARTS LIST


INPUT FILTER MODULE
A1
21014-1
+28 VDC
INPUT
-28 VDC
GRD
FL1
FL2
HOUSEKEEPING REG INV
A3
PWA 21021-2
21053-1
(BR553)
T1
21054-1
(BR554)
POWER FAIL +
POWER FAIL -
BLU
WHT/BLU
BRN
WHT/BRN
WHT/RED
RED
GRN
WHT/GRN
WHT/YEL
YEL
BLK
WHT/BLK
WHT
VIOL
WHT/VIOL
GRY
2N5682
2N2222A
2N2907A
1N753A
1N821A

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR



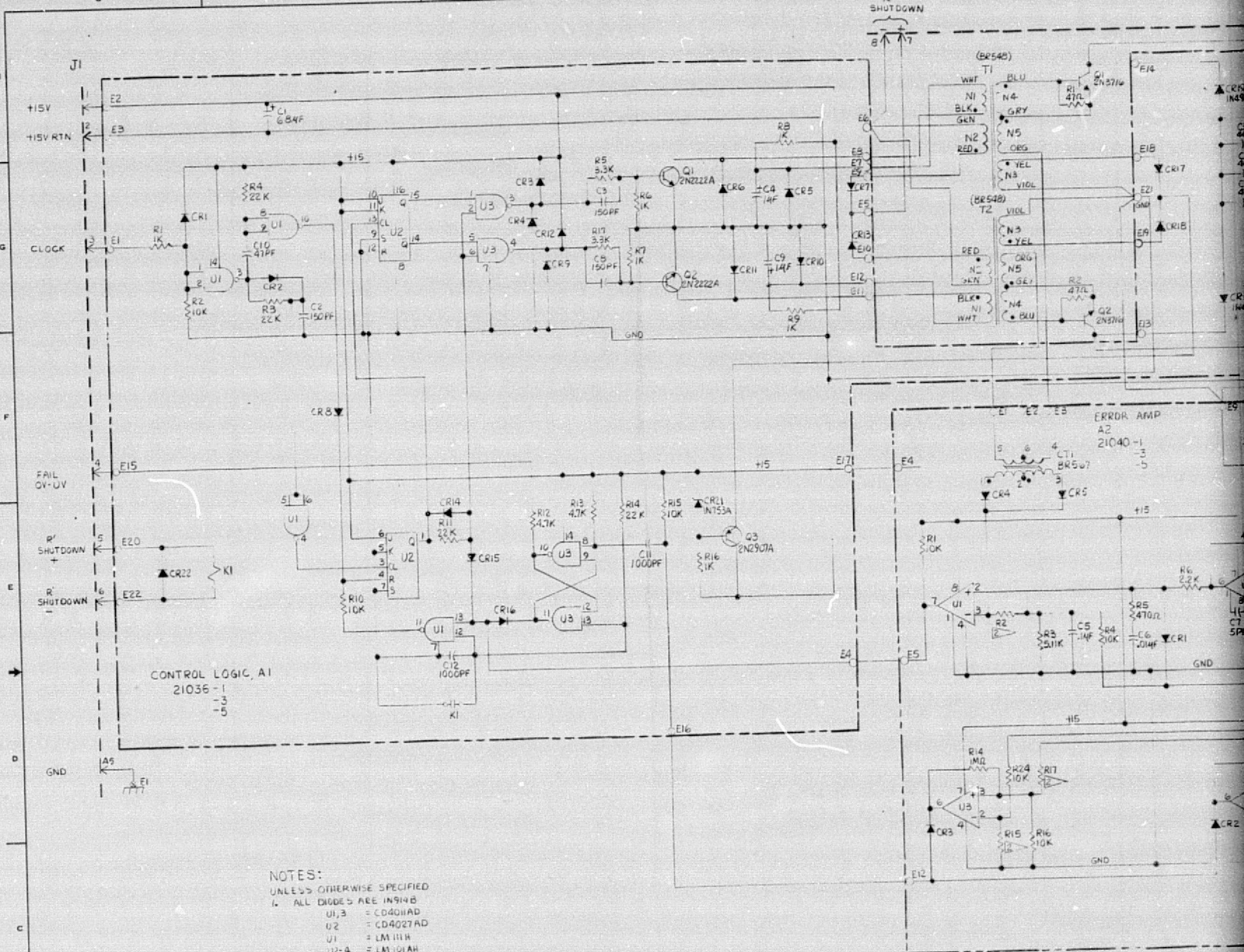
FOLDOUT FRAME

MARTIN MARIETTA CORPORATION

SCHEMATIC
INPUT FILTER AND
HOUSEKEEPING CIRCUITS

E	04236	SK2895E021

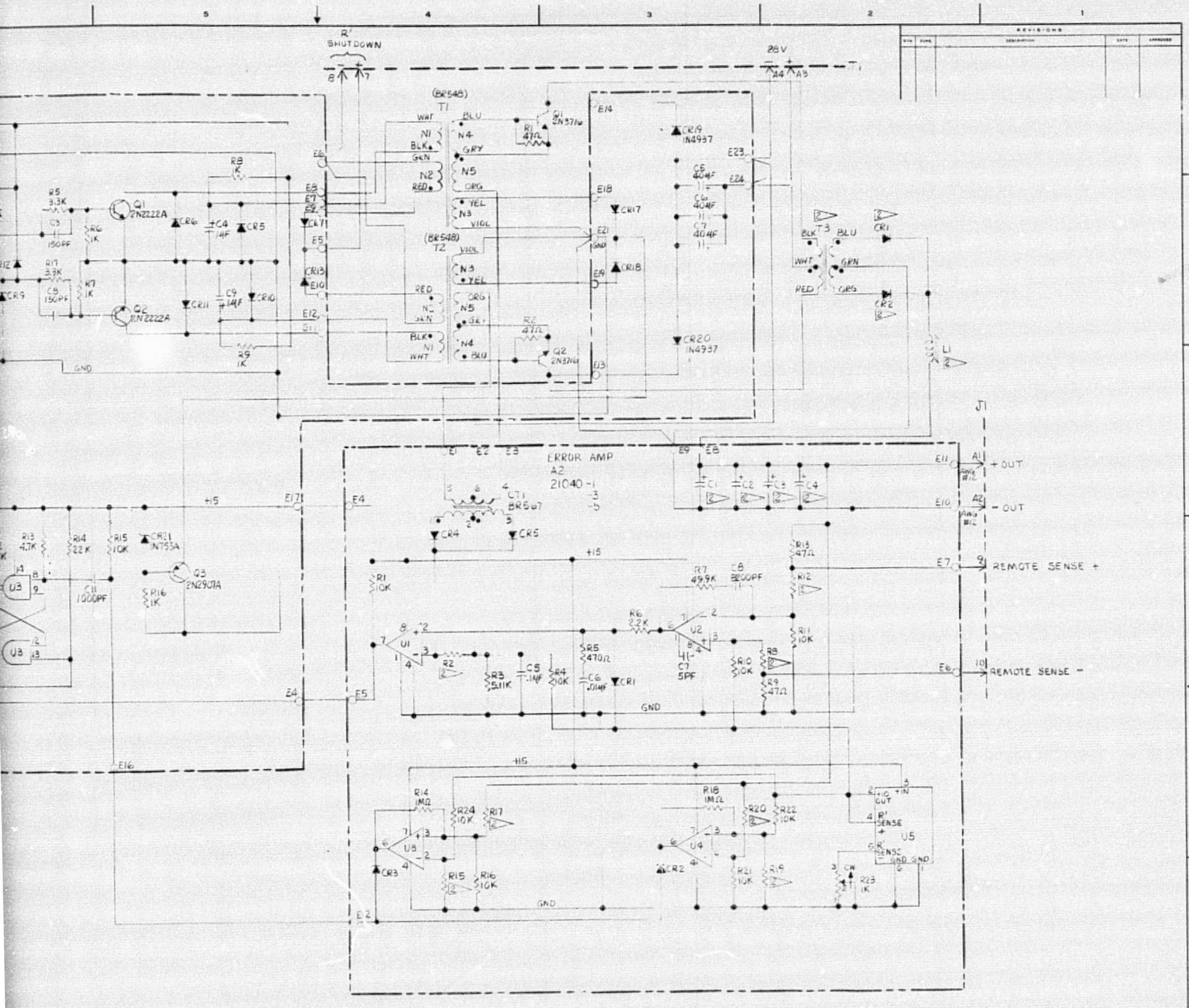
C1&C2



NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIODES ARE IN914B
U1,3 = CD4011AD
U2 = CD4027AD
U1 = LM111H
U2-4 = LM101AH
U5 = AD2700U
2 SEE TABULATION FOR COMPONENT VALUE

IN3891	IN3891	IN5828	CR1,2
21059-1	21058-1	21057-1	L1
21051-1	21050-1	21049-1	T3
-5ASSY (28V)	-3ASSY (15V)	SK28956050-1 ASSY (5V)	REF DES

36.5K±1%,.1W	20.5K±1%,.1W	6.81K±1%,.1W	R19,20
19.6K±1%,.1W	10K±1%,.1W	3.32K±1%,.1W	R15,17
2K±1%,.3W	15K±.1%,.3W	499K±.1%,.3W	R8,12
15μF,50V	47μF,35V	220μF,10V	C1-4
21040-5 ASSY (28V)	21040-3 ASSY (15V)	21040-1 ASSY (5V)	REF DES



1N5828	CR1,2
21057-1	L1
21049-1	T3
SK26956050-1 ASSY (5V)	REF DES

6.81K±1% J.W.	R19,20
3.32K±1% J.W.	R15,17
499K±1% .3W	R8,12
220μF,10V	C1-4
21040-1 ASSY (5V)	REF DES

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

FOLDOUT FRAME 2

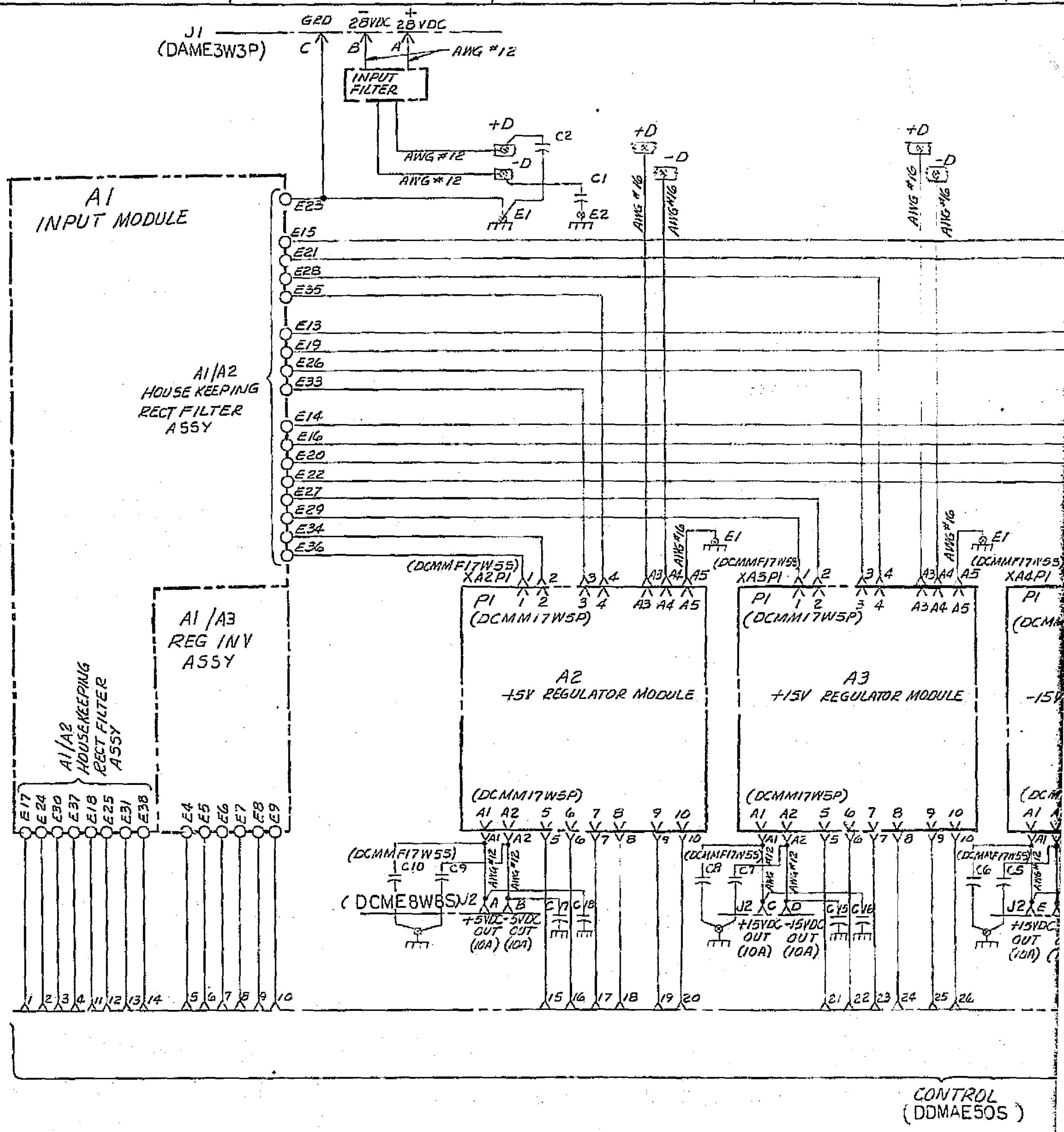
MARTIN MARIETTA CORPORATION

SCHEMATIC
MULTI-OUTPUT POWER SUPPLY (±5V, ±15V, ±28V) OUTPUT REG

E 04236 SK26956031

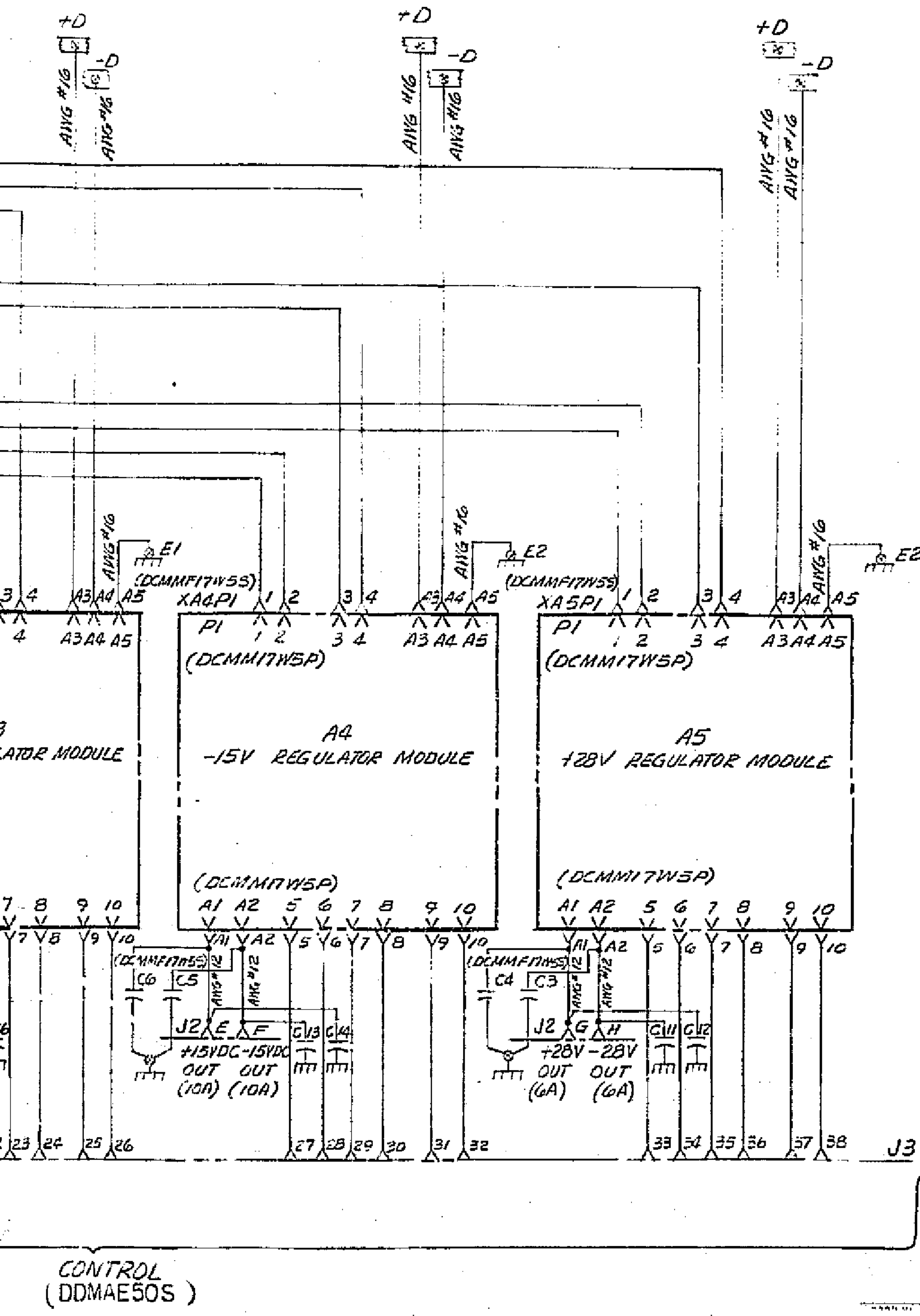
SCALE NONE SHEET 1 OF 1

C3&C4



FOLDOUT FRAME

REVISIONS				
LTR.	ZONE	DESCRIPTION	DATE	APPROVED



REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

NOTES:
1. UNLESS OTHERWISE SPECIFIED ALL WIRE TO BE AWG#20.
2. THE SPECIFICATION OF C1 THRU C10 IS .22 μF, 200V.
3. THE SPECIFICATION OF C11 THRU C18 IS .1 μF, 100V.

FOLDOUT FRAME 2

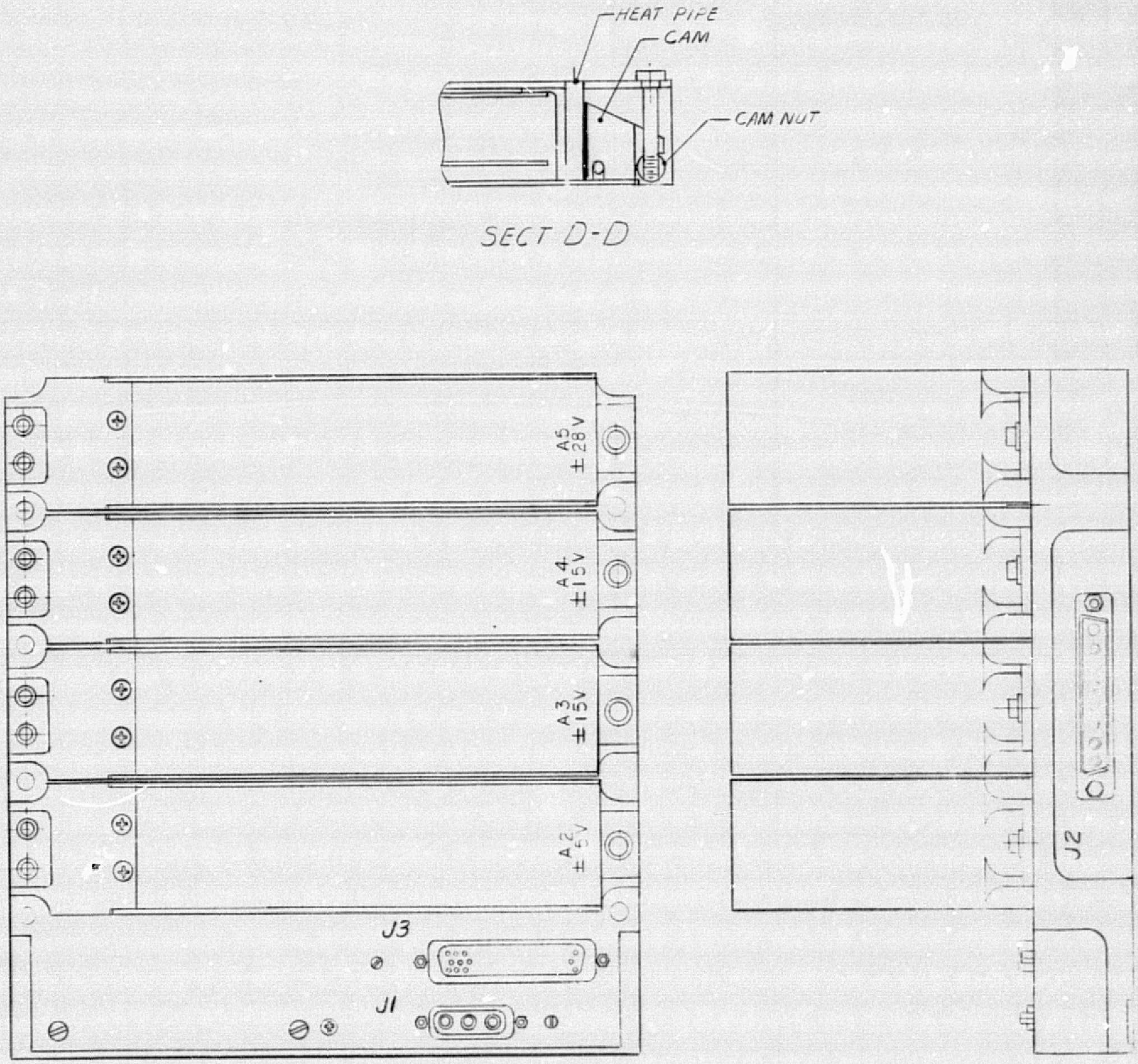
MARTIN MARIETTA CORPORATION

POST OFFICE BOX 179, DENVER, COLORADO

SCHEMATIC-
MULTI-OUTPUT POWER SUPPLY

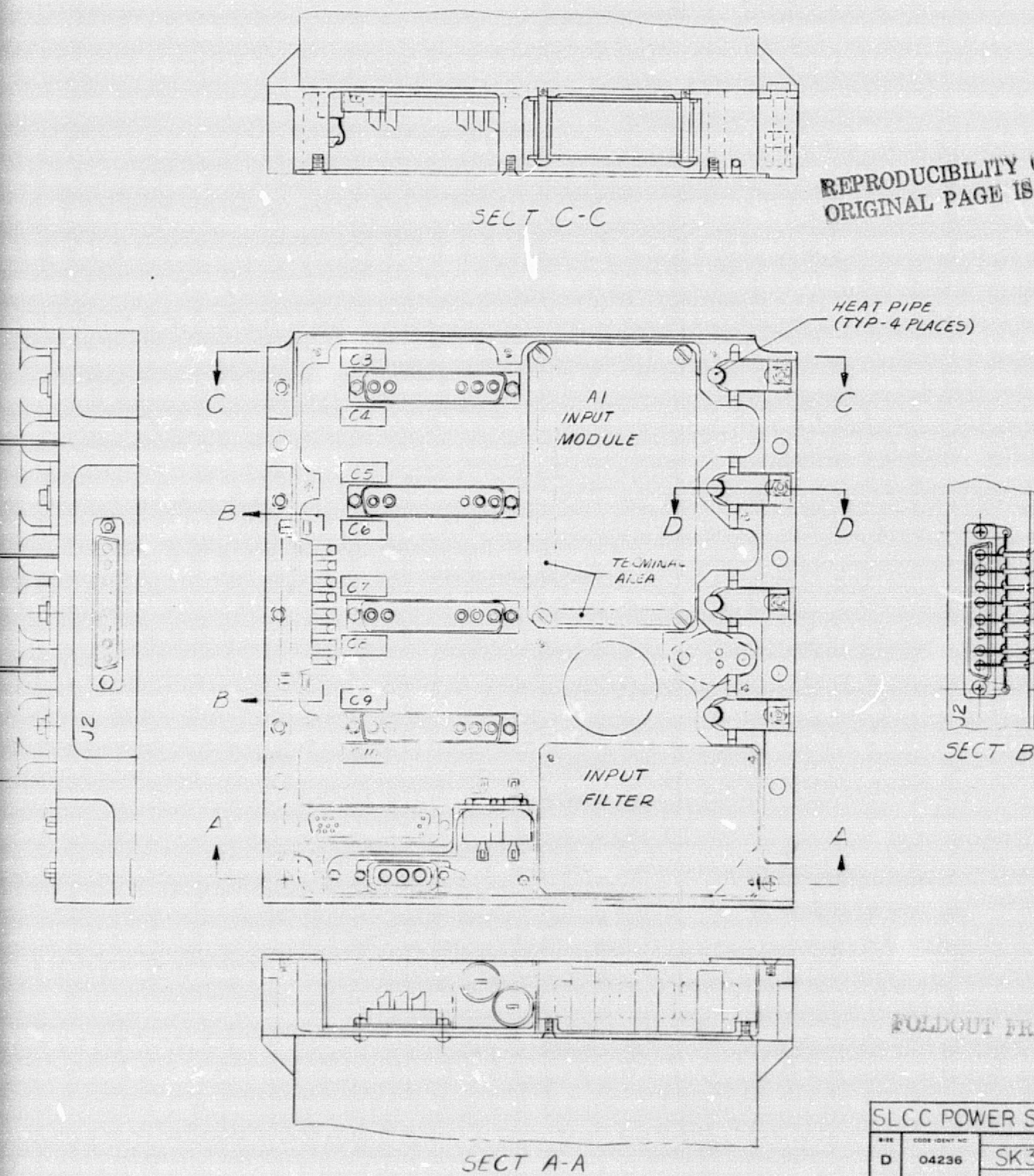
SIZE	CODE IDENT NO	
D	04236	SK28956011
SCALE	—	SHEET 1

1C5&C6



FOLDOUT FRAME

REVISIONS				
SYM.	ZONE	DESCRIPTION	DATE	APPROVED



FOLDOUT FRAME 2

SLCC POWER SUPPLY ASSY		
SIZE D	CODE IDENT NO 04236	SK3179901
SCALE		SHEET

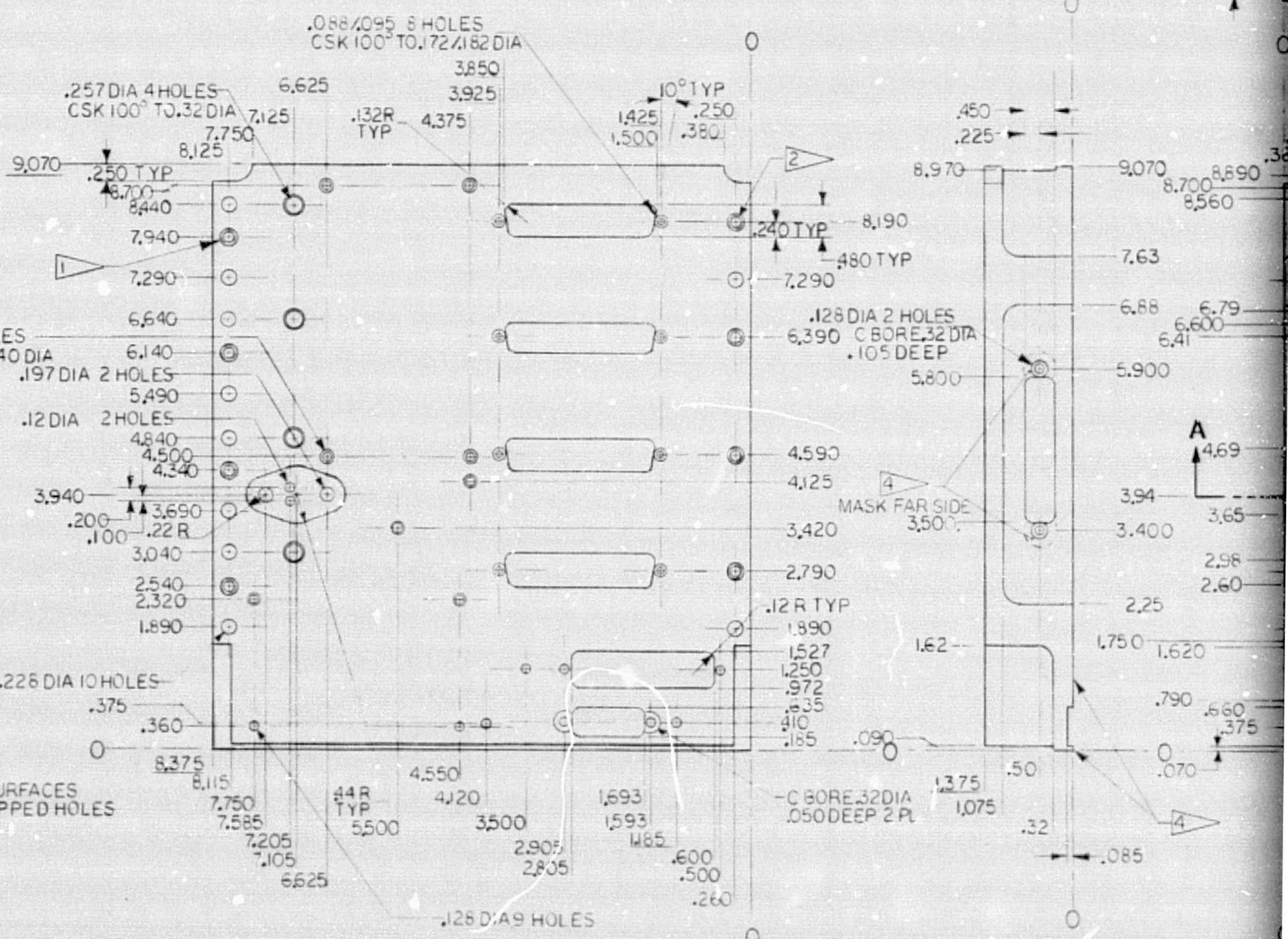
C7&C8

NOTES

1. DRILL .2010 DIA .62 DEEP 4 HOLES
CSK TO .22/.25 DIA
TAP W/#3FPAH3 .57 DEEP
INSTALL HELICOIL #1191 3CN - 0285

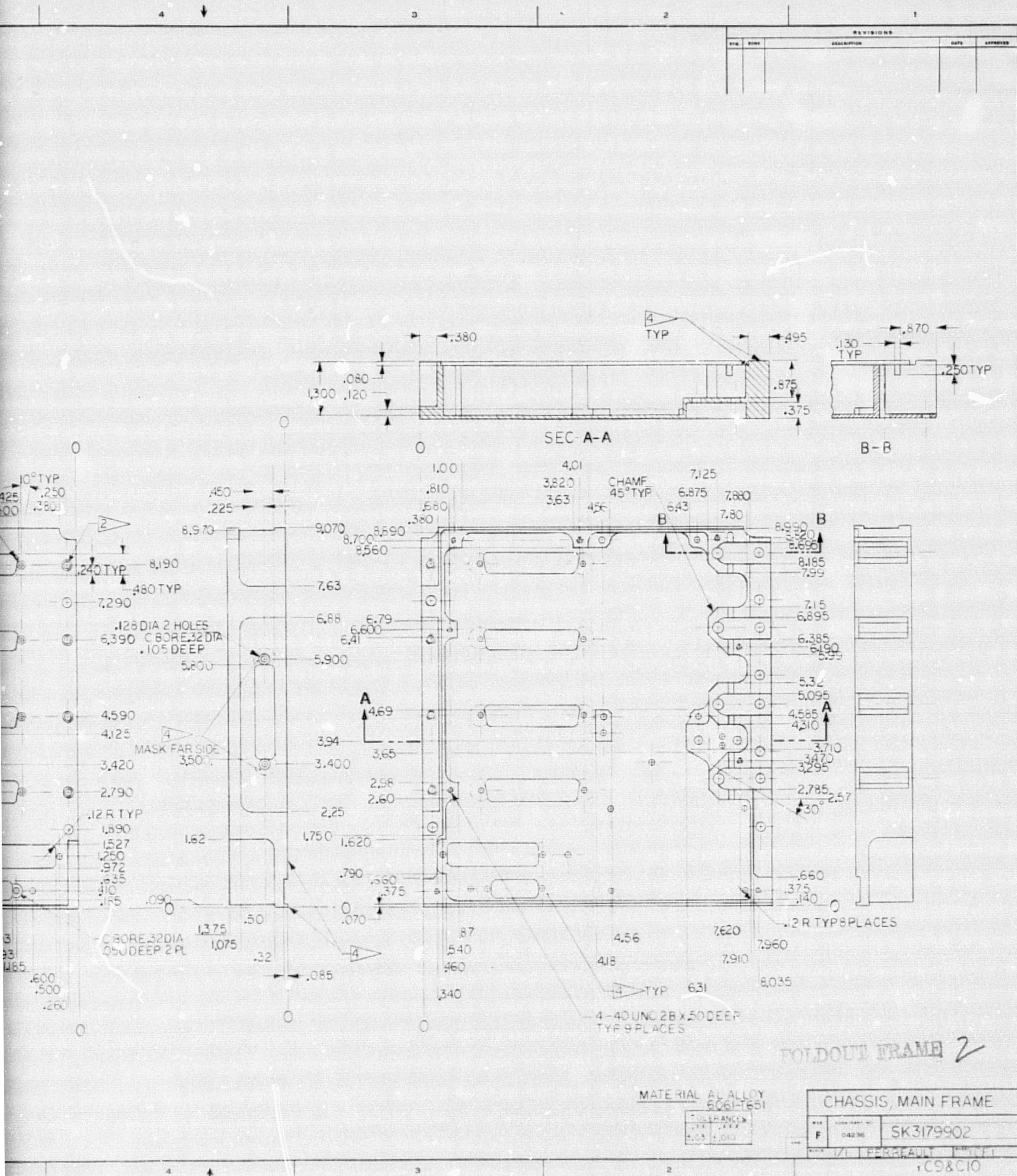
2. SAME AS ABOVE EXCEPT
DRILL AND TAP THRU 4 HOLES

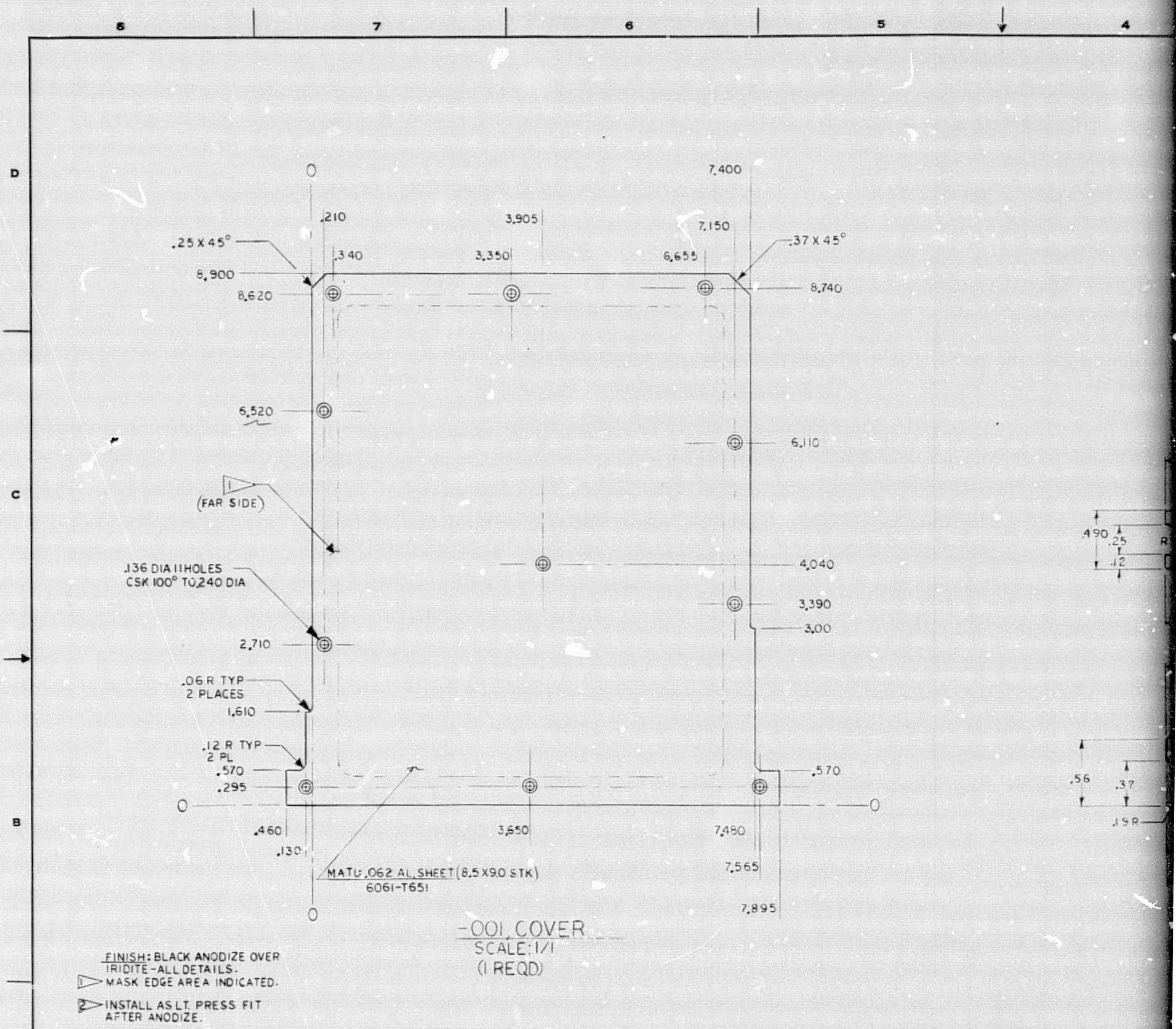
3. ALL RADII .25 EXCEPT AS NOTED



4. FINISH: BLACK ANODIZE
OVER IRIDITE, MASK SURFACES
INDICATED AND ALL TAPPED HOLES
PRIOR TO ANODIZE

FOLDOUT FRAME


REVISIONS
SEC A-A
B-B
CHAMF 45° TYP
.128 DIA 2 HOLES C BORE .32 DIA .105 DEEP
MASK FAR SIDE
.12 R TYP
C BORE .32 DIA .050 DEEP 2 PL
.12 R TYP 8 PLACES
4-40 UNC 2B X .50 DEEP TYP 9 PLACES
MATERIAL AL ALLOY 6061-T651
TOLERANCES
CHASSIS, MAIN FRAME
SK3179902
1/1
FERREAULT
C9 & C10



FINISH: BLACK ANODIZE OVER IRIDITE-ALL DETAILS.

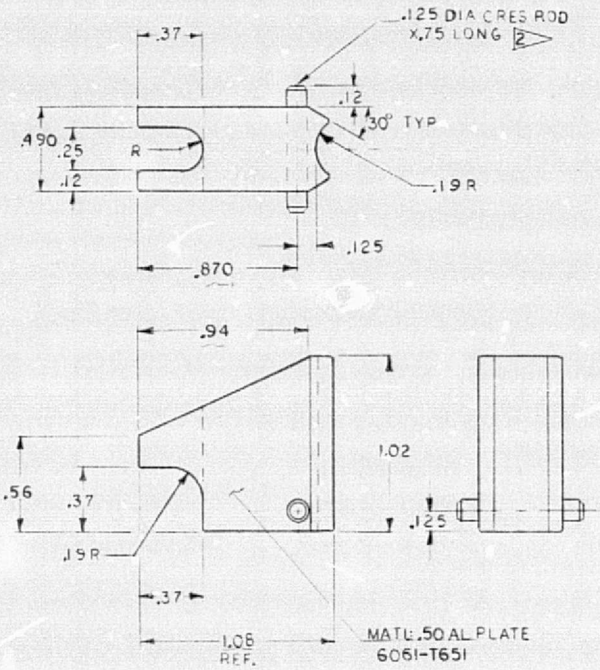
1 MASK EDGE AREA INDICATED.

2 INSTALL AS LT. PRESS FIT AFTER ANODIZE.

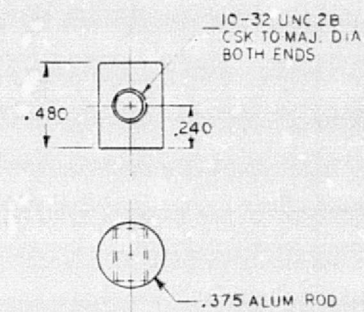
FOLDOUT FRAME 1

SYM.	ZONE	DESCRIPTION	DATE	APPROVED
A		-001 REVISED COMPLETELY; -002 LENGTH	7/2/76	DTP

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR



-002 CAM
SCALE: 2X
(4 REQD)



-003 NUT
SCALE: 2X
(4 REQD)

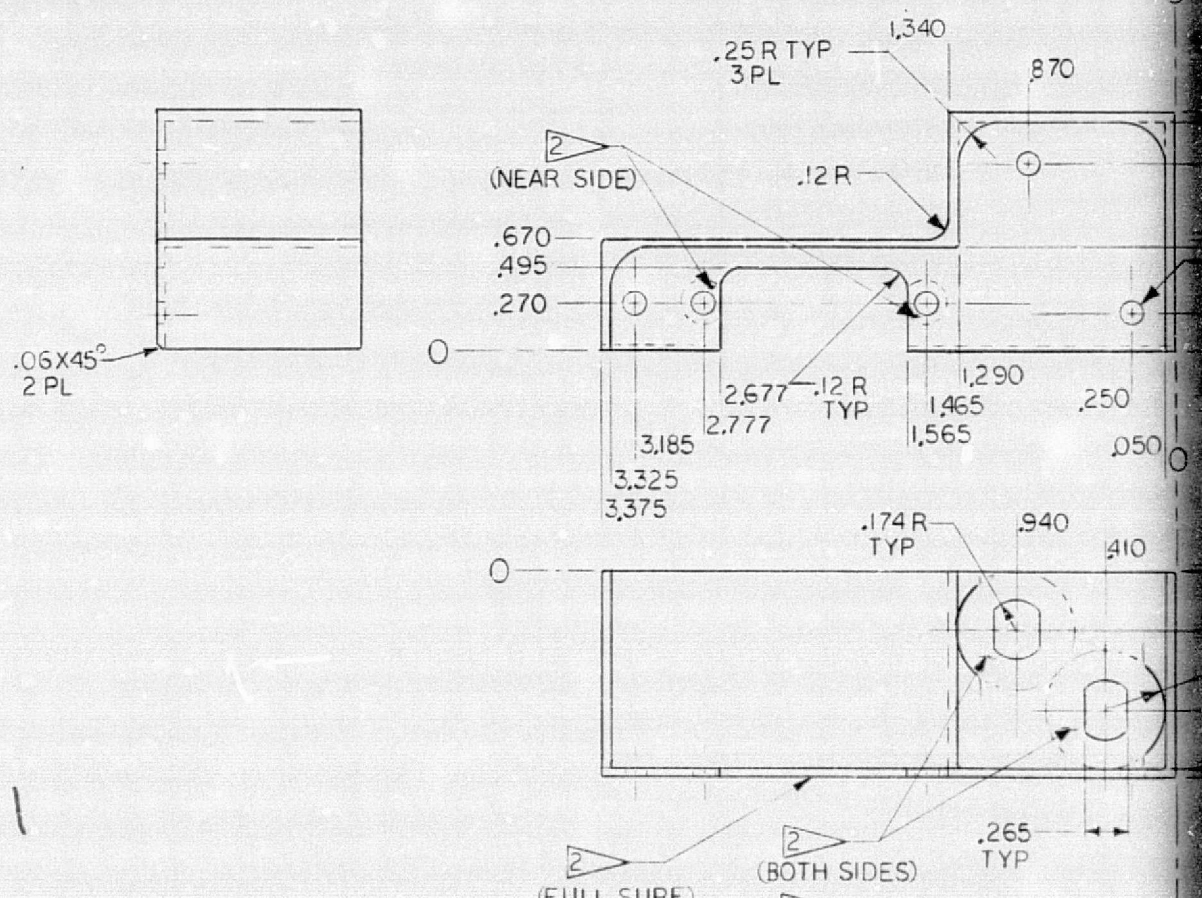
FOLDOUT FRAME 2

CHASSIS DETAILS M.F.		
SIZE D	CODE IDENT NO. 04236	SK28956056
SCALE NOTED	WTF	SHEET

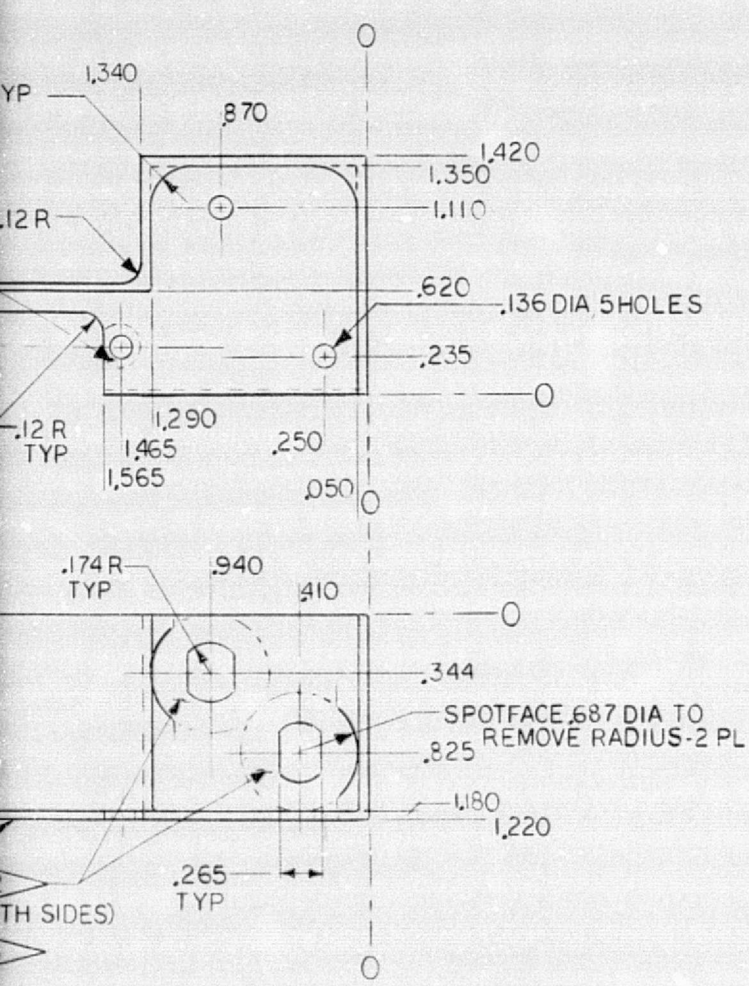
C11 & C12

NOTES

1. MATERIAL: AL ALLOY 6061-T651
2. FINISH: BLACK ANODIZE OVER IRIDITE. MASK SURFACES INDICATED BEFORE ANODIZE.
3. DOUBLE 'D' HOLES MAY BE ROTATED TO ACCOMODATE TOOLING.



FOLDOUT FRAME 1



REVISIONS

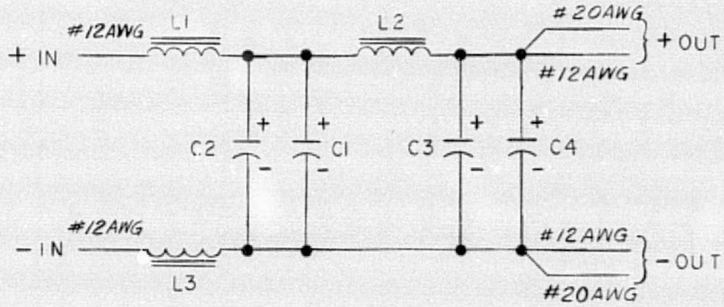
SYM.	ZONE	DESCRIPTION	DATE	APPROVED

FOLDOUT FRAME 2

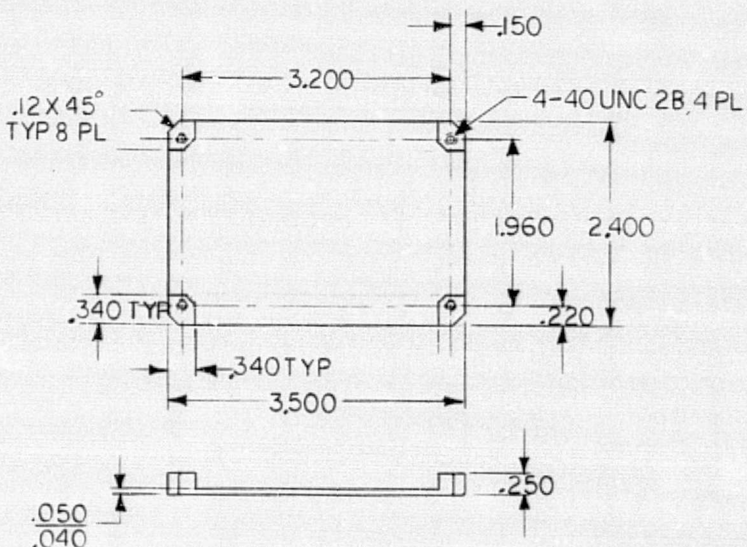
LINE FILTER SUBCHASSIS

SIZE	CODE IDENT NO	
D	04236	SK3179903
SCALE 2/1	D PERREAULT	7-1-76

C13&C14

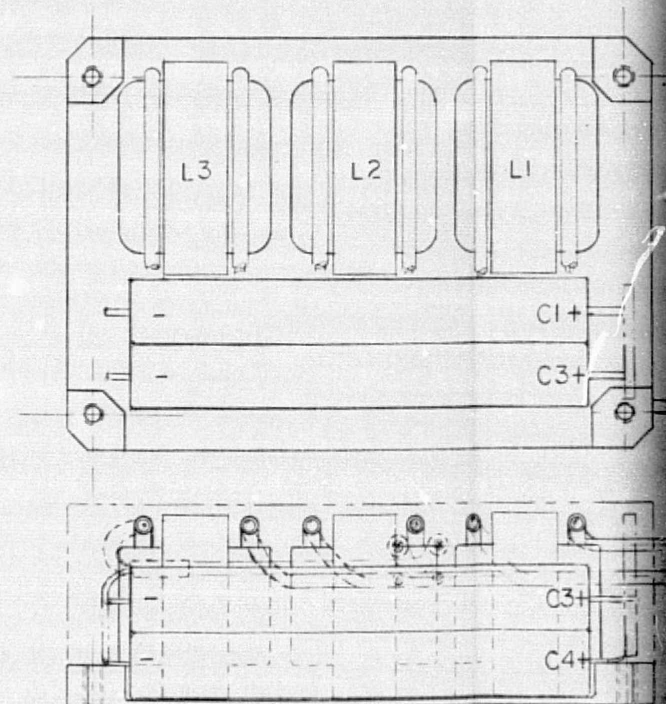


SCHEMATIC



BASE PLATE

AL ALLOY 6061-T6,
IRIDITE

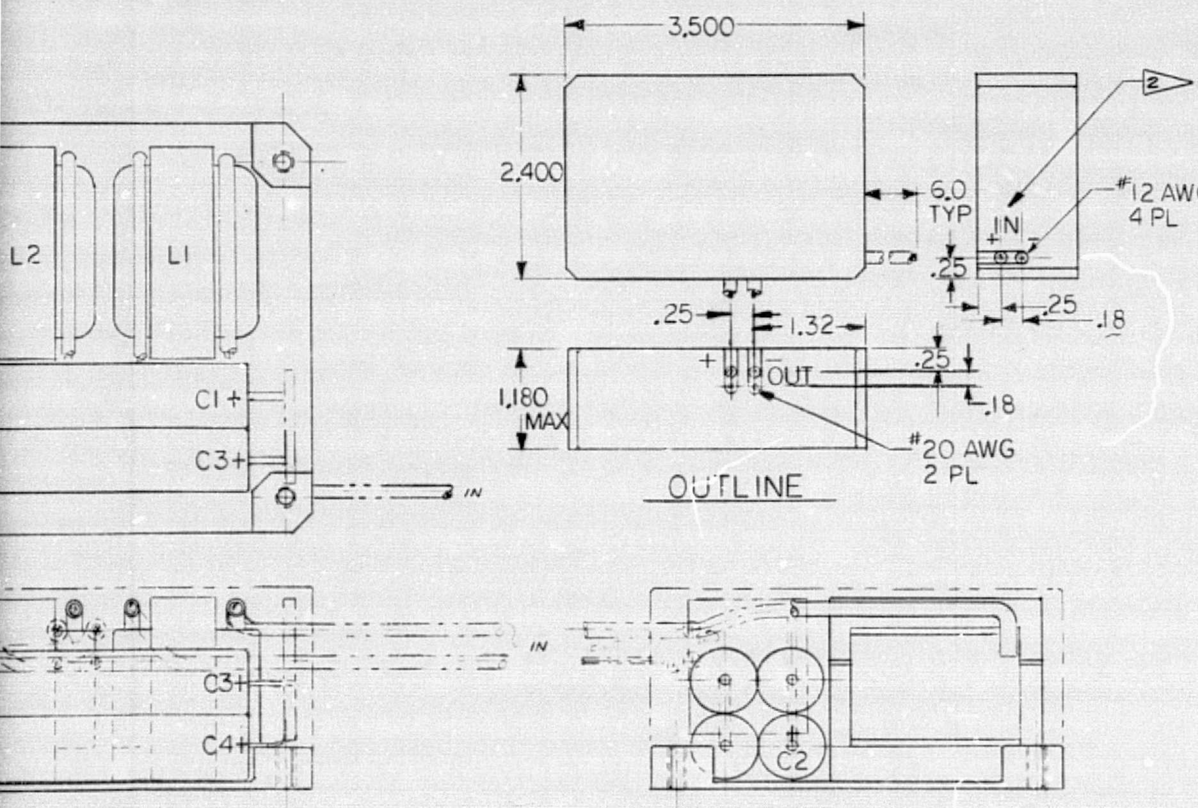


ASSY

SCALE 2/1

REVISIONS				
SYM.	ZONE	DESCRIPTION	DATE	APPROVED

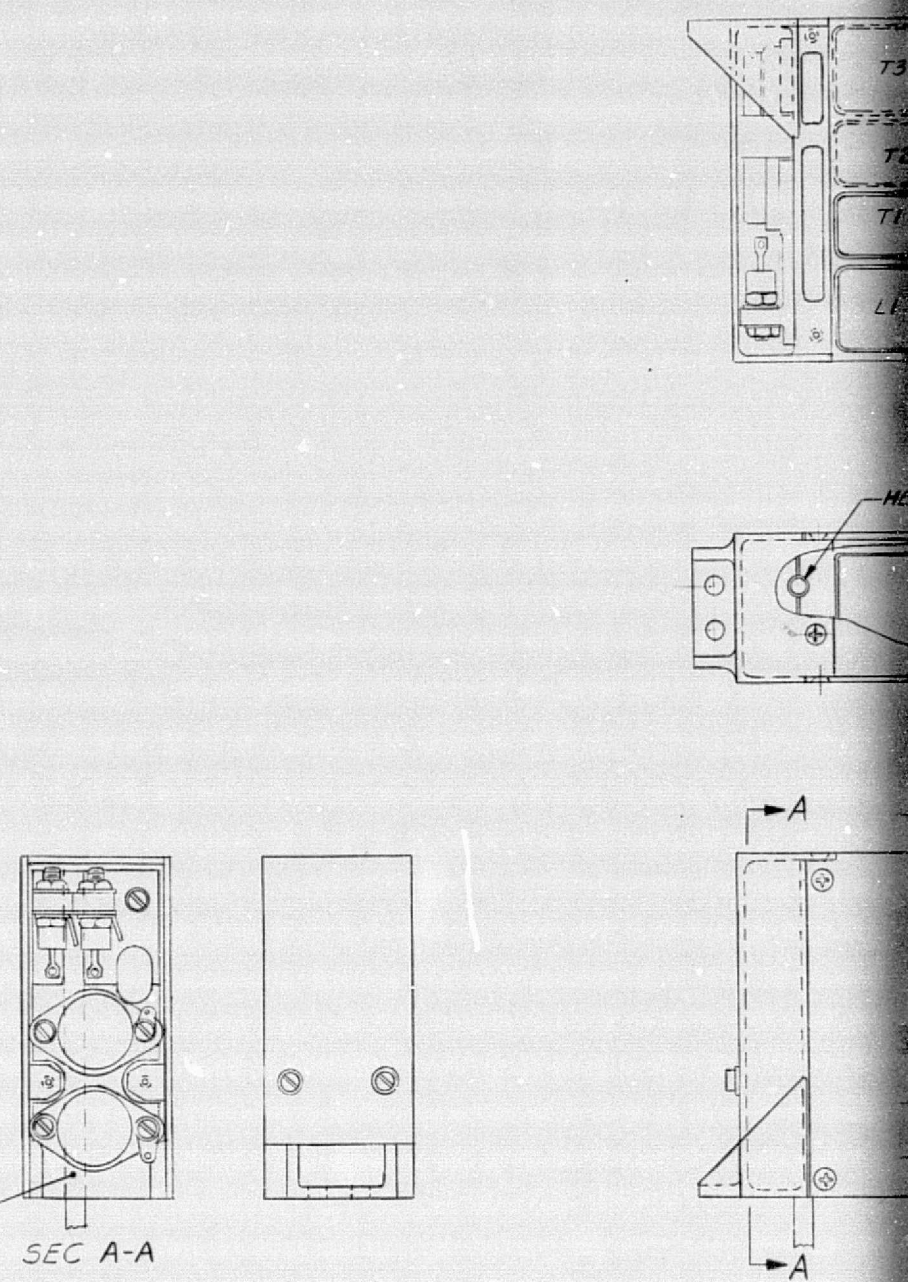
NOTES:
1. POSITION COMPONENTS AS SHOWN. BOND L1, L2 & L3 TO BASE DETAIL WITH EC 2216. WIRE PER SCHEMATIC. ENCAPSULATE ASSEMBLY TO DIMENSIONS SHOWN.
2. MARK, USING .09 HIGH CHARACTERS. LOCATE APPROX AS SHOWN.



FOLDOUT FRAME 2

INPUT FILTER ASSY		
SIZE	CODE IDENT NO	
D	04236	SK3179904
SCALE		PERREAULT 7-1-?

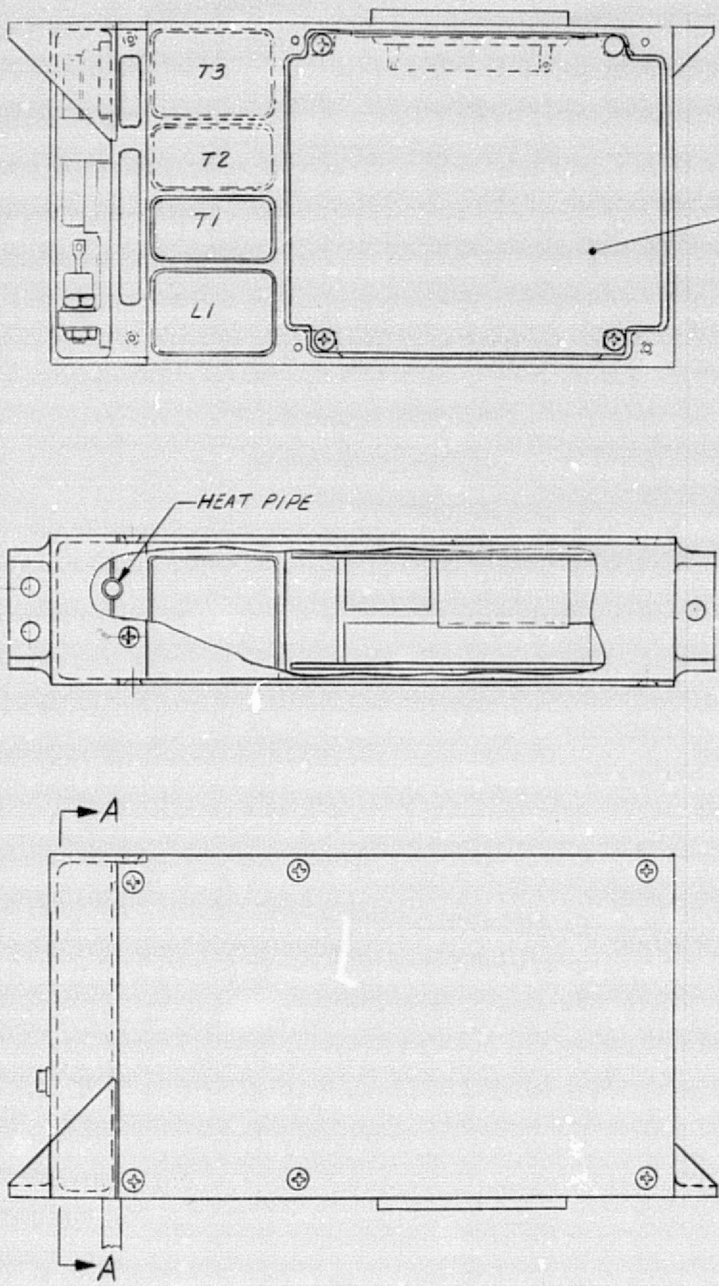
1C15&C16



FOLDOUT FRAME

SYM.	ZONE	DESCRIPTION	DATE	APPROVED

REVISIONS

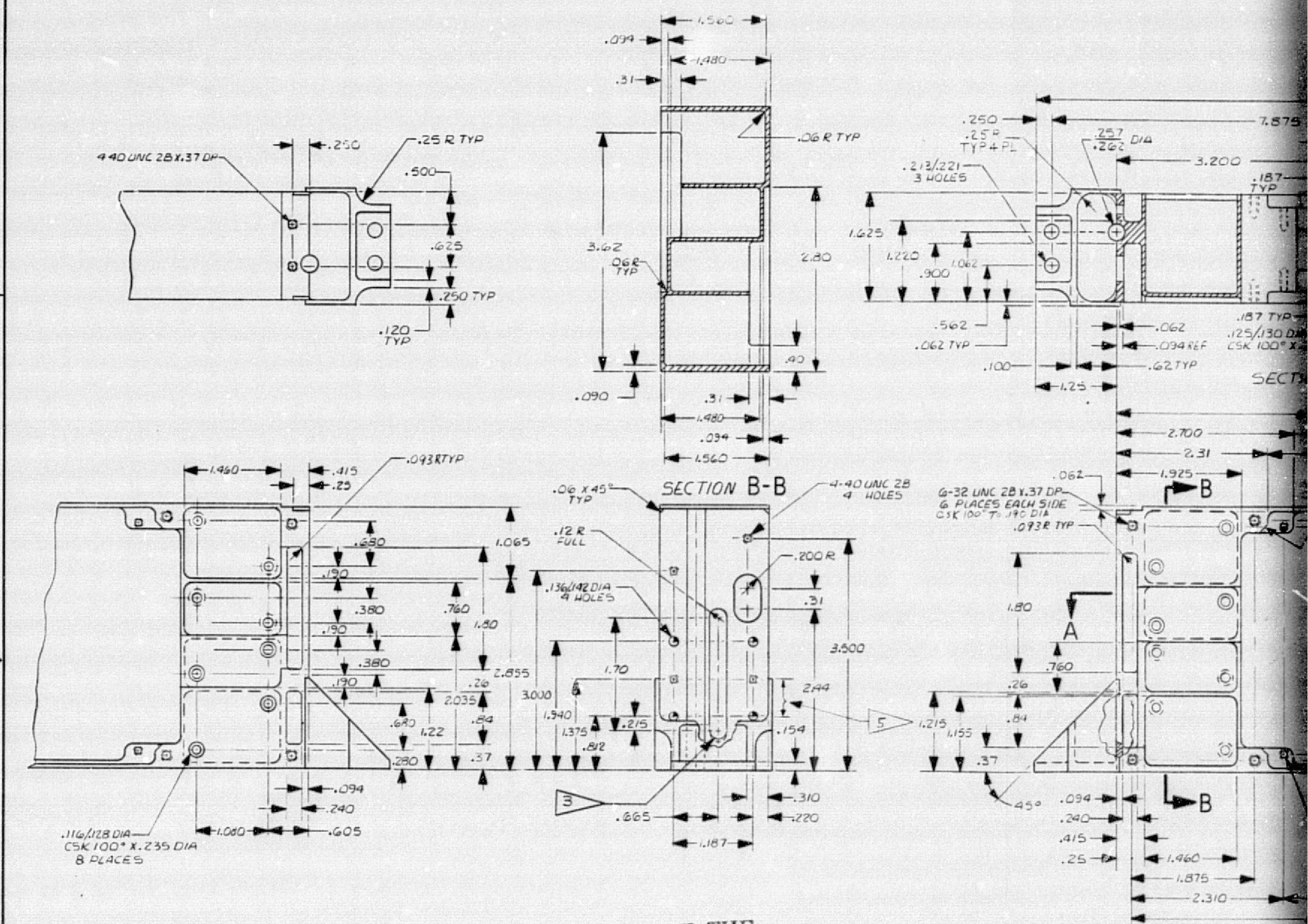


FOLDOUT FRAME 2

OUTPUT REGULATOR ASSY

SIZE	CODE IDENT NO	
D	04236	SK28956050
SCALE		SHEET

C17&C18



5 RADIUS TO BE .12 MAX THIS AREA SEE ZONE 4D

4 FINISH: ANODIZE DYE BLACK. MASK SURFACES INDICATED

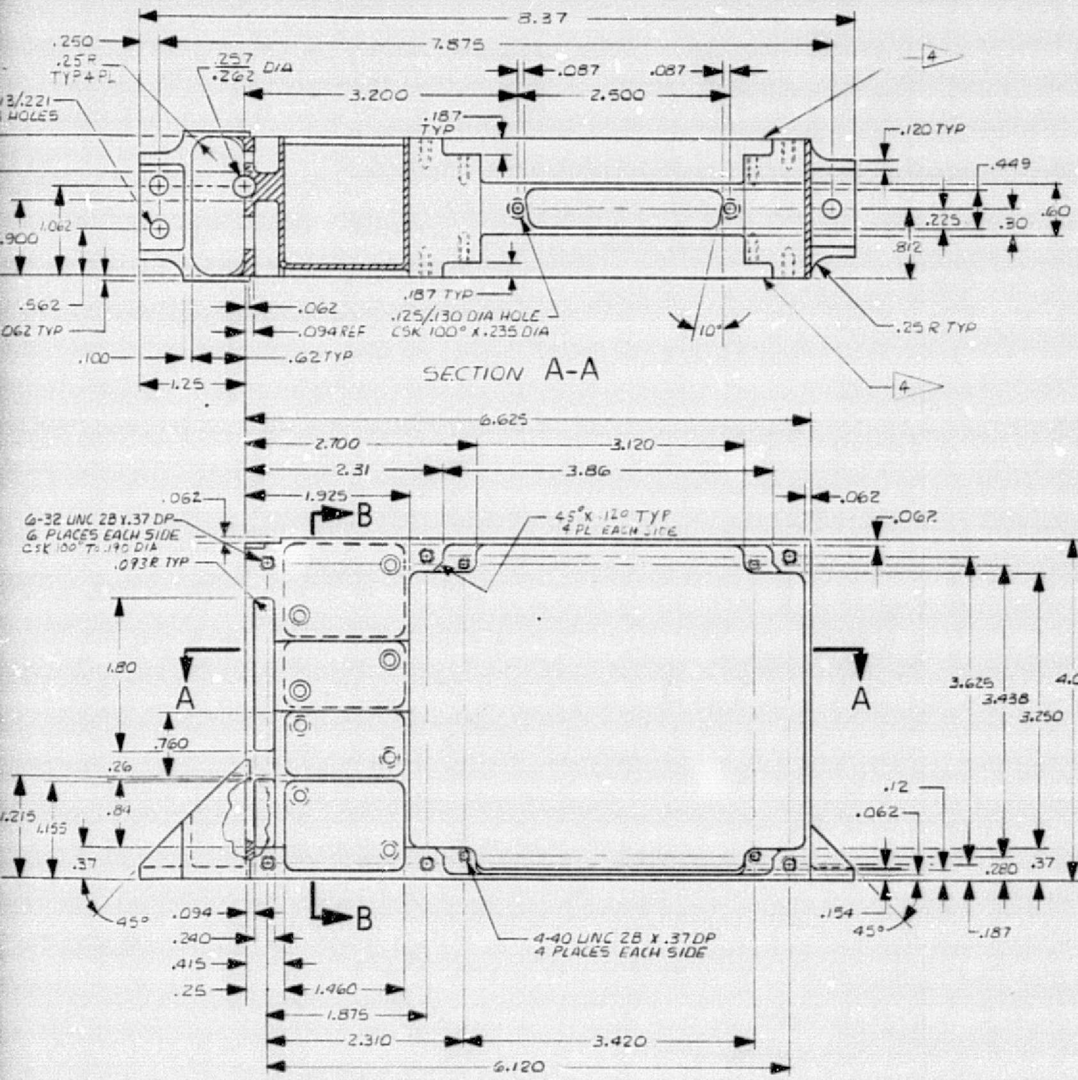
3 DRILL OFF AXIS TO CLEAR MOUNTING FOOT GUSSET.

2. ALL RADII .12 EXCEPT AS NOTED.

1 BREAK SHARP EDGES.

NOTES:

REVISIONS				
SYM.	ZONE	DESCRIPTION	DATE	APPROVED



FOLDOUT FRAME 2

5K28956051

QUANTITY/DASH NO.	PART NO.	ZONE	REV SYM	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	ISSUE COND	MATERIAL SPECIFICATION	FINISH OR MFR CODE	CHG
	-001			CHASSIS	875 X 4.25 X 1.75	AL ALLOY 6061-T651				

ODD DASH NO. SHOWN — EVEN DASH NO. OPP — LIST OF MATERIAL

EFFECTIVE ON	CALC WT	DASH NUMBER	NEXT ASSY	USED ON	FINAL ASSY	TEST
			APPLICATION		QTY REQD	

DIMENSIONING REF MIL-STD-8
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING
TOLERANCES ON:

FRACTIONS	DECIMALS .X	.XX	.XXX	ANGLES
± 1/32	± .1	± .03	± .010	± 1/2°

MACHINED SURFACES REF - MIL-STD-10
MIL-I-8500 STATUS
INTERCHANGEABLE
REPLACEABLE
UNCONTROLLED

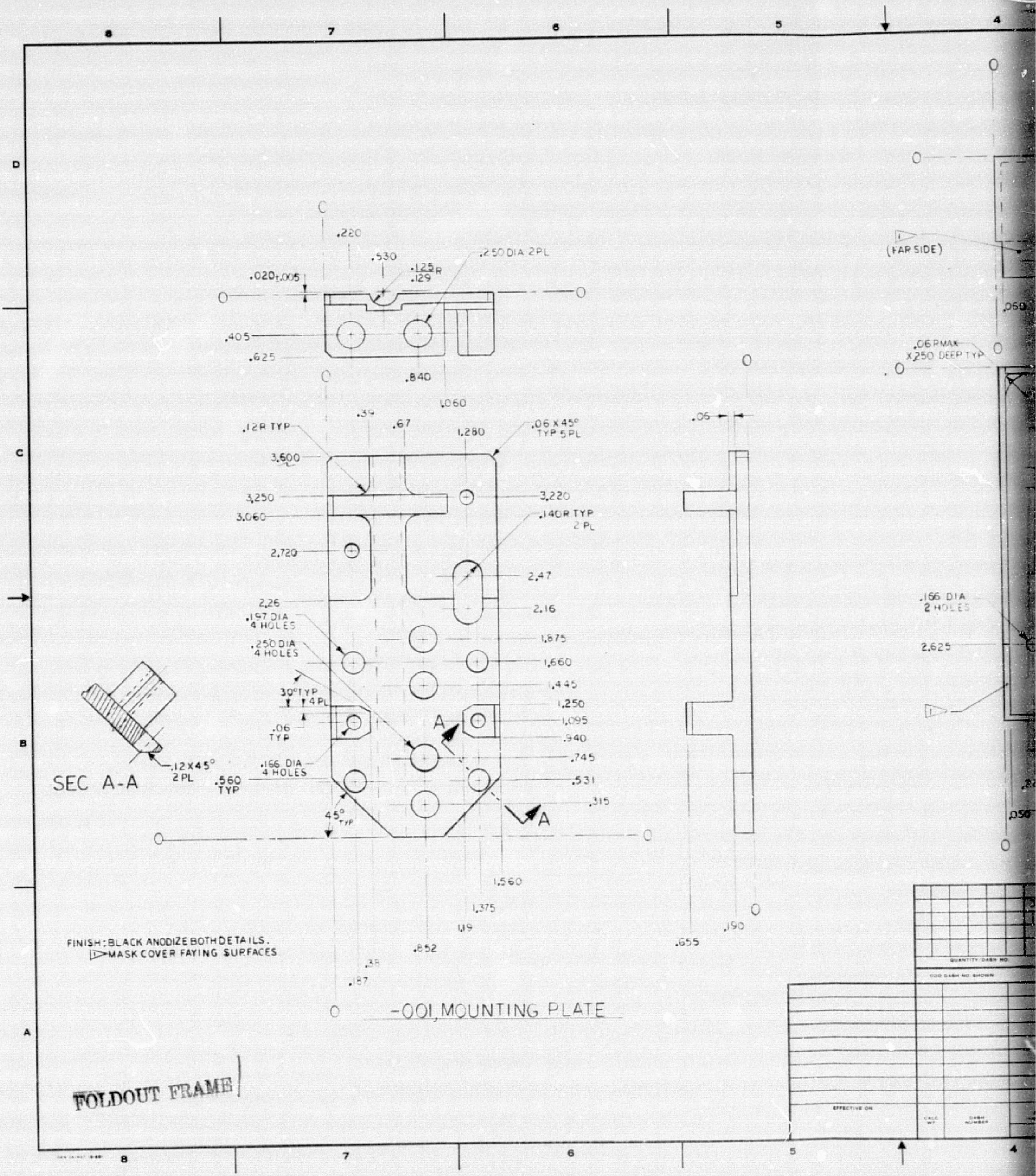
DRAWN BY: [illegible] DATE 4-15-76
CHECKER
STRESS ENGR
WT ENGR
MATL ENGR
RELIABILITY
GR ENGR
PROJECT
CUST APPROVAL

MARTIN MARIETTA CORPORATION
POST OFFICE BOX 179, DENVER, COLORADO

CHASSIS
OUTPUT REGULATOR
MSFC STD POWER SUPPLY

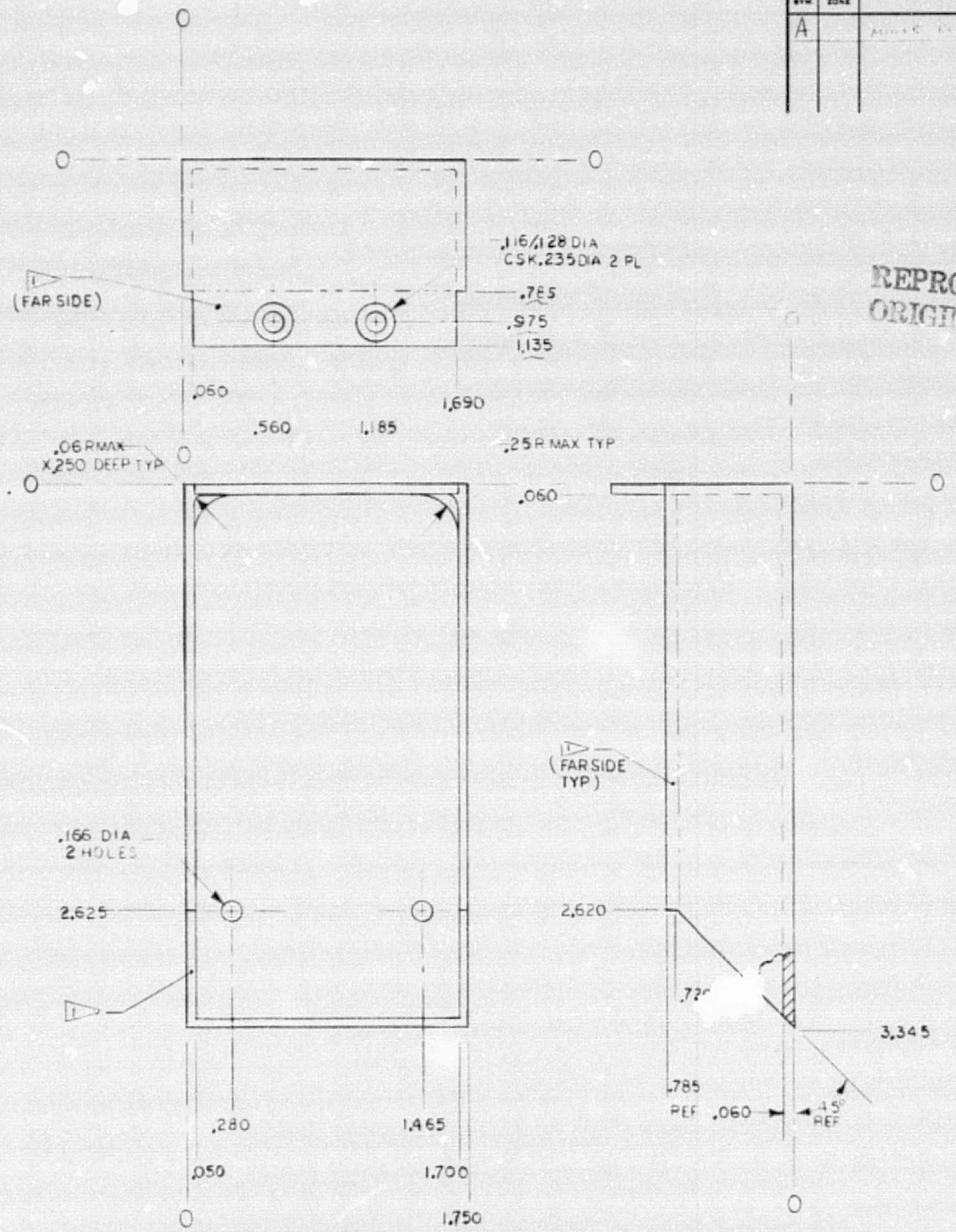
SIZE	CODE IDENT NO.	
D	04236	5K28956051
SCALE FULL		SHEET 1 OF 1

1C19&C20



.220
.530
.250 DIA 2PL
.020±.005
.125
.129 R
.405
.625
.840
1.060
.39
.67
1.280
.12R TYP
.06 X 45° TYP 5 PL
3.600
3.250
3.060
3.220
.140R TYP 2 PL
2.720
2.47
2.26
2.16
.197 DIA 4 HOLES
.250 DIA 4 HOLES
1.875
1.660
1.445
30° TYP 4 PL
1.250
1.095
.940
.745
.531
.315
.06 TYP
.166 DIA 4 HOLES
.560 TYP
45° TYP
A
SEC A-A
.12 X 45° 2 PL
1.560
1.375
1.19
.852
.38
.187
.06
.655
.190
(FAR SIDE)
.06 R MAX X .250 DEEP TYP
.166 DIA 2 HOLES
2.625
FINISH: BLACK ANODIZE BOTH DETAILS.
MASK COVER FAYING SURFACES
-001, MOUNTING PLATE
FOLDOUT FRAME
QUANTITY DASH NO.
EFFECTIVE ON

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
A		[illegible]	[illegible]	[illegible]



-002, END COVER

QUANTITY/DASH NO	PART NO.	ZONE	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	MATERIAL SPECIFICATION	FINISH OR MFR CODE
1	-002		END COVER	2X4X1.25 TH	6061-T651 ALUM		
1	-001		MOUNTING PLATE	2X4X1.00 TH	6061-T651 ALUM		

ODD DASH NO SHOWN — EVEN DASH NO OPP — LIST OF MATERIAL

DIMENSIONING REF MIL-STD-8
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING
TOLERANCES ON:

FRACTIONS	.X	.XX	.XXX	ANGLES
± 1/32	± .1	± .03	± .010	± 1/2°

MACHINED SURFACES REF: MIL-STD-10

MARTIN MARIETTA CORPORATION
POST OFFICE BOX 179, DENVER, COLORADO

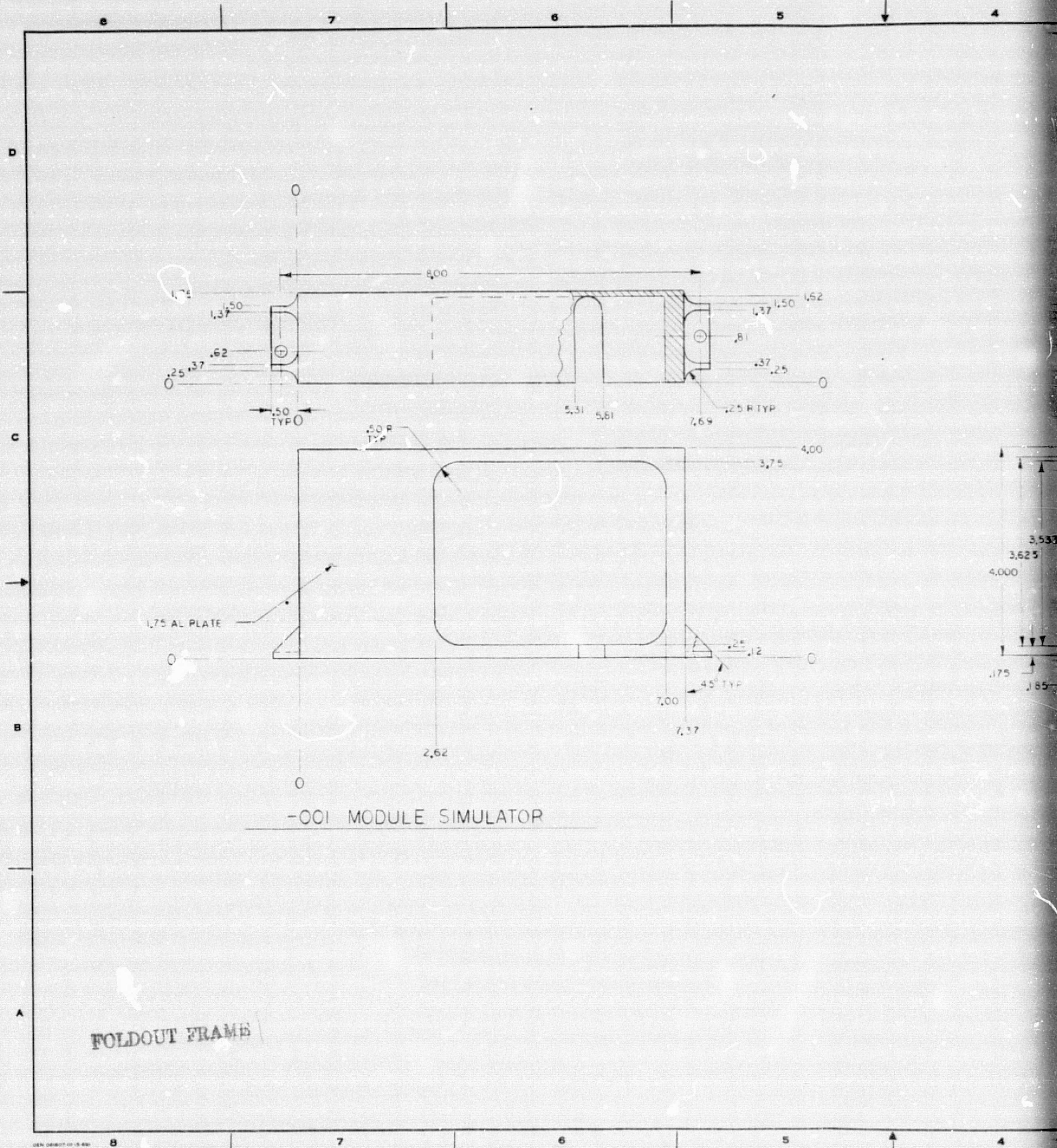
CHASSIS DETAILS, OUTPUT REGULATOR

W. PERREAULT

SIZE	CODE IDENT NO.	
D	04236	SK28956052

SCALE 2X

C21&C22



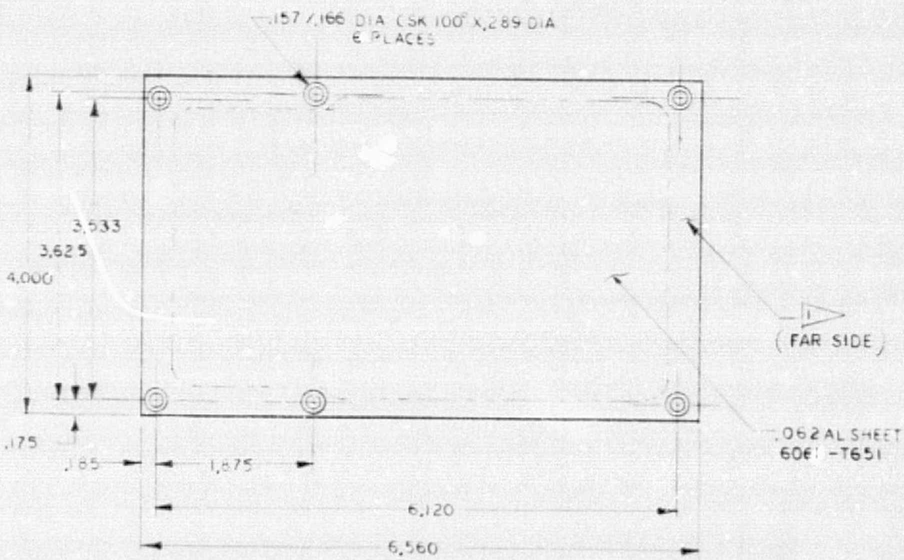
-001 MODULE SIMULATOR

FOLDOUT FRAME

5 4 3 2 1

REVISIONS

SYM.	ZONE	DESCRIPTION	DATE	APPROVED
A	B3	CH DIM & ADDED FINISH	7-2-76	[illegible]



-002 COVER, SHOWN
-003 OPPOSITE
(4 EACH REQD)

FOLDOUT FRAME 2

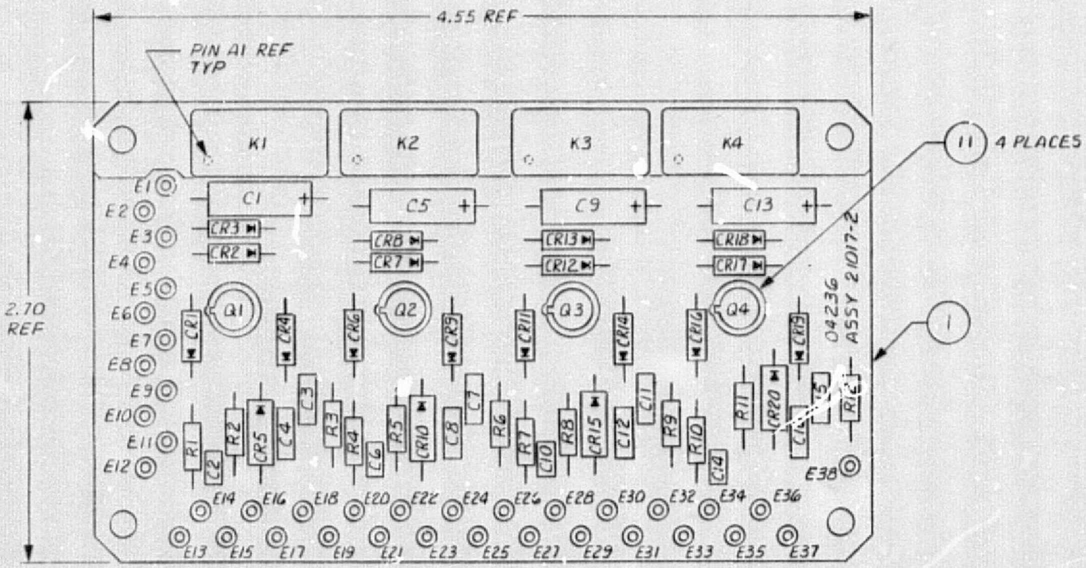
FINISH: BLACK ANODIZE OVER IRIDITE
MASK AREA INDICATED APPROX AS SHOWN

MODULE DETAILS		
SIZE: D	CODE IDENT NO: 04236	SK28956053
SCALE: FULL		SHEET

C23 & C24

5 4 3 2

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED



NOTES:
1. PRINTED WIRING ASSEMBLY SHALL BE CONSTRUCTED PER GOOD COMMERCIAL PRACTICE
2. PARTIAL REF DES ARE SHOWN, FOR COMPLETE REF DES PREFIX WITH ASSEMBLY NO.
3. REFERENCE DRAWINGS:
   SCHEMATIC E21011
   PRINTED WIRING BOARD C21019

-2 SHOWN
SEPARATE PARTS LIST SEE APL 21017

C25

DIMENSIONING REF: MIL-STD-8
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING
TOLERANCES ON:

FRACTIONS	DECIMALS .X	.XX	.XXX	ANGLES
±1/32	±.1	±.03	±.010	±1.2

MACHINED SURFACES
REF: MIL-STD-10
MIL-1-8500 STATUS
INTERCHANGEABLE
REPLACEABLE
UNCONTROLLED

		DEPT	DATE
DRAWN BY	F.IKEYA	0546	76 APR 14
CHECKER			
STRESS ENGR			
WT ENGR			
MATL ENGR			
RELIABILITY			
GR ENGR			
PROJECT			
CUST APPROVAL			

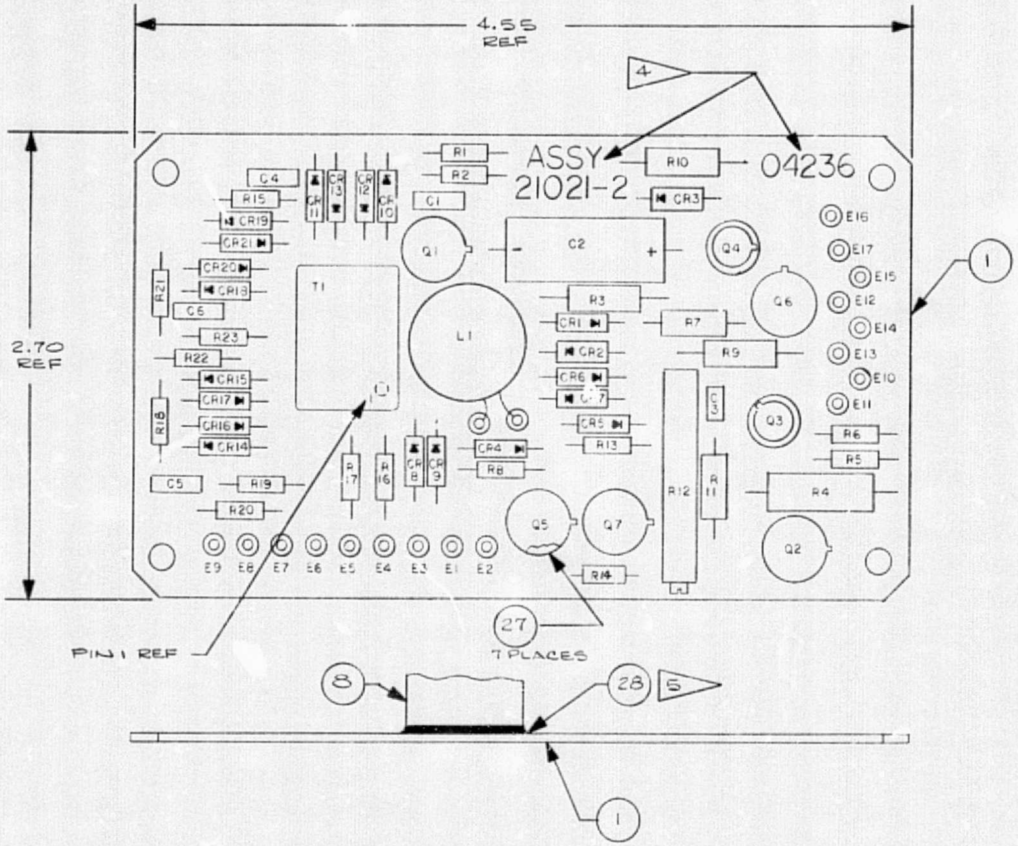
MARTIN MARIETTA CORPORATION
POST OFFICE BOX 179, DENVER, COLORADO

PRINTED WIRING ASSEMBLY
HOUSEKEEPING RECT FILTER

SIZE	CODE IDENT NO	
C	04236	21017
SCALE 2/1		SHEET 1 OF 1

DEN 081605-01 (2-69)

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED



NOTES:

1. PRINTED WIRING ASSEMBLY SHALL BE CONSTRUCTED PER GOOD COMMERCIAL PRACTICE
2. PARTIAL REF DES ARE SHOWN, FOR COMPLETE REF DES PREFIX WITH ASSEMBLY NO.
3. REFERENCE DRAWINGS:
   SCHEMATIC E21011
   PRINTED WIRING BOARD C21023

4 RUBBER STAMP MFG CODE AND ASSY NO. APPROX AS SHOWN USING .12 HIGH CHARACTERS

5 BOND ITEM 8 TO ITEM 1 USING ITEM 28 PER MFG INSTRUCTIONS

-2 SHOWN
SEPARATE PARTS LIST SEE APL 21021

DIMENSIONING REF MIL-STD-8
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING
TOLERANCES ON:

FRACTIONS	DECIMALS .X	.XX	.XXX	ANGLES
±1/32	±.1	±.03	±.010	±1/2°

MACHINED SURFACES REF: MIL-STD-10

MIL-I-8500 STATUS
INTERCHANGEABLE
REPLACEABLE
UNCONTROLLED

DRAWN BY	DEPT	DATE
F. IKEYA	0546	76 APR 14

CHECKER
STRESS ENGR
WT ENGR
MAT'L ENGR
RELIABILITY
GR ENGR
PROJECT
CUST RPRSNTV

MARTIN MARIETTA CORPORATION
POST OFFICE BOX 179, DENVER, COLORADO

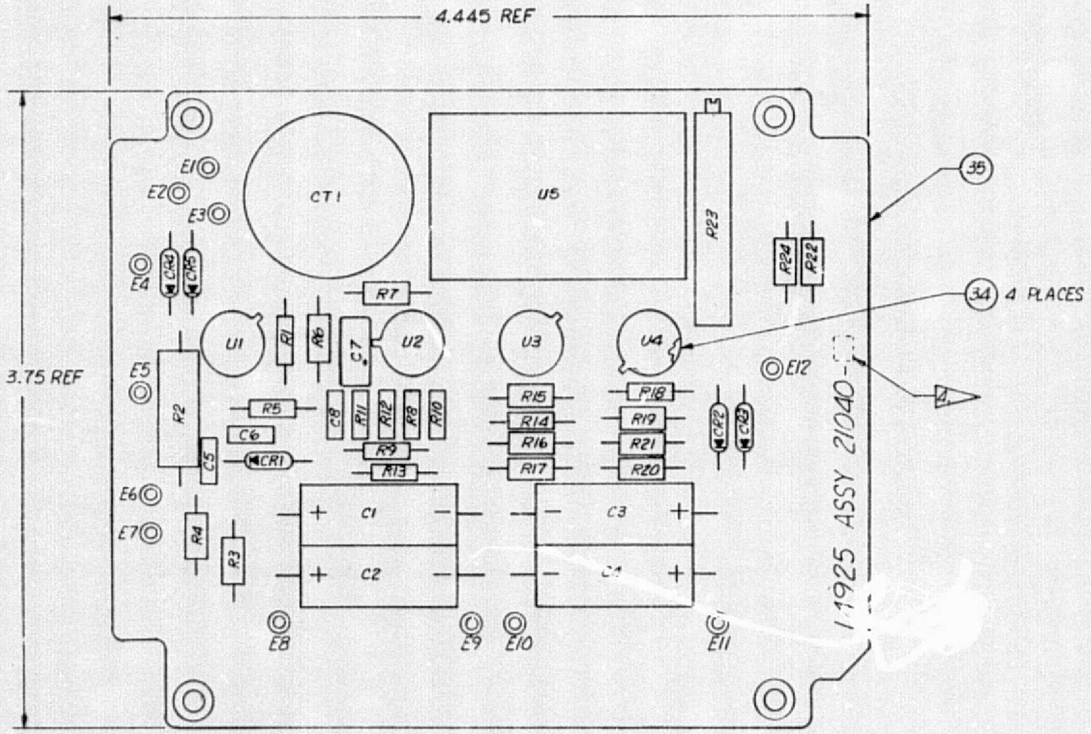
PRINTED WIRING ASSEMBLY
HOUSEKEEPING REG INV

SIZE	CODE IDENT NO	
C	04236	21021
SCALE 2/1		SHEET 1 OF 1

C26

DEN 061605-01 (2-69)
DEN 061626 (10-68)

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
3-C	A	DELETE C9	7-14-76	WTP



NOTES:

1. PRINTED WIRING ASSEMBLY SHALL BE CONSTRUCTED PER GOOD COMMERCIAL PRACTICE
2. PARTIAL REF DES ARE SHOWN, FOR COMPLETE REF DES PREFIX WITH ASSEMBLY NO.
3. REFERENCE DRAWINGS:
   SCHEMATIC E21026
   PRINTED WIRING BOARD C21042
4. RUBBER STAMP APPROPRIATE DASH NO. USING .12 HIGH CHARACTERS

-1,-3,-5 SHOWN

ASSEMBLE PER SEPARATE PARTS LIST SEE APL 21040

ITEM OR FIND NO.	QTY REQ	CODE IDENT NO.	PART NO. OR IDENTIFYING NO.	DRAWING OR SPECIFICATION NO.	NOMENCLATURE OR DESCRIPTION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON FRACTIONS ± ~ DECIMALS .xx ± ~ .xxx ± ~ ANGLES ± ~

MATERIAL ~

FINISH ~

CONTRACT NO.

APPROVED		DATE
PROJECT ENGR		
DRAWN	[illegible]	10-27-74
CHECKED		

TELEDYNE BROWN ENGINEERING
Research Park • Huntsville, Alabama 35807

TITLE PRINTED WIRING ASSEMBLY ERROR AMPLIFIER

SIZE	CODE IDENT NO.	DWG NO.
C	14925	21040

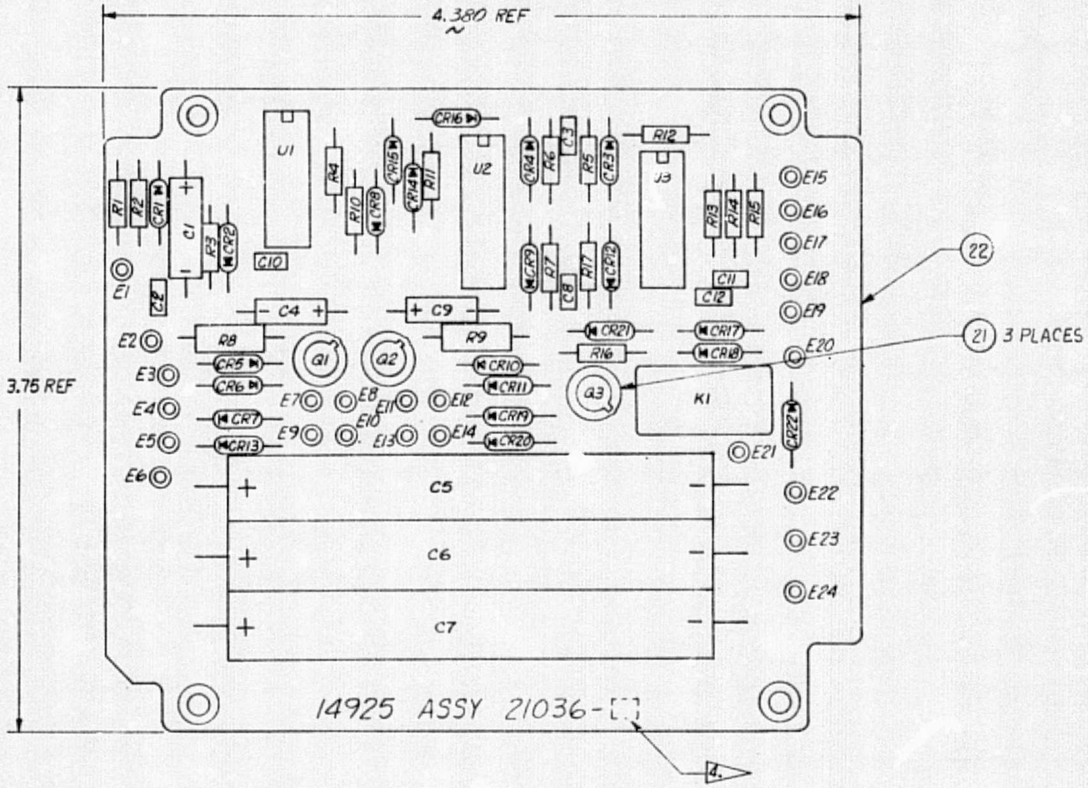
SCALE 2/1 WEIGHT ~ SHEET OF

NEXT ASSY	QTY REQ	USED ON

APPLICATION

FORM NO. 2372

C27



NOTES:

1. PRINTED WIRING ASSEMBLY SHALL BE CONSTRUCTED PER GOOD COMMERCIAL PRACTICE
2. PARTIAL REF DES ARE SHOWN, FOR COMPLETE REF DES PREFIX WITH ASSEMBLY NO.
3. REFERENCE DRAWINGS:
   SCHEMATIC E21026
   PRINTED WIRING BOARD C21038
4. RUBBER STAMP APPROPRIATE DASH NO. USING .12 HIGH CHARACTERS

-1,-3,-5 SHOWN

ASSEMBLE PER SEPARATE PARTS LIST SEE APL 21036

ITEM OR FIND NO.	QTY REQ	CODE IDENT NO.	PART NO. OR IDENTIFYING NO.	DRAWING OR SPECIFICATION NO.	NOMENCLATURE OR DESCRIPTION

PARTS LIST

NEXT ASSY	QTY REQ	USED ON
APPLICATION		

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON:
FRACTIONS ± ~ DECIMALS .xx ± ~ .xxx ± ~ ANGLES ± ~

MATERIAL ~

FINISH ~

CONTRACT NO.

APPROVED		DATE
PROJECT ENGR		
DRAWN	23	10-27-74
CHECKED		

TELEDYNE BROWN ENGINEERING
Research Park • Huntsville, Alabama 35807

TITLE PRINTED WIRING ASSEMBLY CONTROL LOGIC

SIZE	CODE IDENT NO.	DWG NO.
C	14925	21036

SCALE 2/1 WEIGHT ~ SHEET 1 OF 1

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

FORM NO. 2372

C28

Standard Load Center Converter

Sheet 1 of 1	Parts List			Standard Load Center Converter			PL3179901
Item Number	Quantity Required -1	-3	-5	Code Ident No.	Part No. or Identification No.	Nomenclature or Description	Remarks
1	1				SK3179902-1	Chassis, Main Frame	Used on A1 Assembly
2	1				SK28956050-1	Output Regulator Assy	A2 (5V)
3	2				SK28956050-3	Output Regulator Assy	A3, A4 (15V)
4	1				SK28956050-5	Output Regulator Assy	A5 (28V)
5	1				SK3179904-1	Input Filter Assy	A1A1
6	1				21017-1	PWA, Housekeeping Rectifier Filter	A1A2
7	1				21021-1	PWA, Housekeeping Regulator Inverter	A1A3
8	1			14925	21053-1	Transformer	T1
9	1				2N4900	Transistor	Q1
10	1			Cannon	Dame3W3P	Connector, Input	J1
11	1			Cannon	DCME8W8S	Connector, Output	J2
12	1			Cannon	DDMAE50S	Connector	J3
13	3			Cannon	DM53745-7	Contacts, Power	No. 12 Plug
14	16			Cannon	DM53744-6	Contacts, Power	No. 12 Recep
15	12			Cannon	DM53744-1	Contacts, Power	No. 8 Recep
16	4			Cannon	DCMF17W5S	Connector, O/R	XA2J1, XA3J1 XA4J1, XA5J1
17	2			ERIE	9933-101-6001	Filter	FL1, FL2
18	8			CDE	MCR2P22	Capacitor, 0.22 μf, 200V	C3-C10
19	8				CK06BX104KM	Capacitor, 0.1 μf, 100V	C11-C18
20	4				SK28956056-002	Cam	Heat Pipe Clamp
21	4				SK28956056-003	Nut	
22	A/R				STMC120	CL 2B GR 40 Silicon Rubber	1/8 Thick
23	1				SK28956056-001	Cover	
24	A/R				E-12	Wire, MIL-W-16878/4	
25	A/R				E-18	Wire, MIL-W-16878/4	
26	A/R				E-20	Wire, MIL-W-16878/4	
27	8				MS2503G-148	Lug, Terminal	
28	6			Cannon	D20418-2	Screw Lock Assy, Female	Use W/J1, J2, J3
29	8				NAS1351-3-8	Cap Screw, Hex Socket	
30	4				NAS1351-3-20	Cap Screw, Hex Socket	
31	19				MS24693-C3	Screw, 100°FLHD	4-40 x 5/16
32	9				MS51957-14	Screw, Pan HD	4-40 x 5/16
33	4				MS35649-244	Nut, Plain Hex	4-40
34	4				AN960C4	Washer Plain	No. 4
35	4				¼ AL HEXSTK	Threaded Spacer,	No. 4-40 x 0.85
36	1				¼ AL HEXSTK	Threaded Spacer	No. 4-40 x 1.10
37	1				¼ AL HEX STK	Threaded Spacer	No. 4-40 x 1.22
38	A/R			Dow Corning	DC-340	Thermal Compound	Module & Heat Pipe Interfaces
39	8				NAS662C2R5	Screw, FLHD, 100°	2-56 x 5/16
40	1			Keystone	4726	Kit, Transistor MTG	TO-66
41	12				AN960C10	Washer, Plain	No. 10

O/R Module Assembly, Standard Load Center Converter

Sheet 1 of 1	Parts List			O/R Module Assembly, Standard Load Center Converter			PL28956050
Item Number	Quantity Required -1	-3	-5	Code Ident No.	Part No. or Identification No.	Nomenclature or Description	Remarks
	+5V	±15V	+38V				
1	1	1	1		SK28956051-1	Chassis	
2	1	1	1		SK28956053-002	Cover	
3	1	1	1		SK28956053-003	Cover	
4	1	1	1		SK28956052-001	Mounting Plate	
5	1	1	1		1350H025-5.2	Heat Pipe, 5.2 in. Long	Stainless Steel and Methanol
6	1				21036-1	P.W.A., Control Logic	A1
7		1			21036-3	P.W.A, Control Logic	A1
8			1		21036-5	P.W.A., Control Logic	A1
9	1				21040-1	P.W.A., Error Ampl	A2
10		1			21040-3	P.W.A., Error Ampl	A2
11			1		21040-5	P.W.A, Error Ampl	A2
12	.	1	1	Cannon	DCMM17W5P	Connector	P1 (See Item 14)
13	2	2	2		2N3716	Transistor	Q1, Q2
14	5	5	5	Cannon	DM53745-27	Power Contacts	Part of Item 12
15	2	2	2		21048-1	Transformer, Base Drive	T1, T2
16	1				21049-1	Transformer, 5-V Output	T3
17		1			21050-1	Transformer, 15-V Output	T3
18			1		21051-1	Transformer, 28-V Output	T3
19	1				21057-1	Choke, 5-V Output	L1
20		1			21058-1	Transformer, 15-V Output	L1
21			1		21059-1	Transformer, 28-V Output	L1
22	2				IN5827	Diode	CR1, CR2
23		2	2		IN3891	Diode	CR1, CR2
24	12	12	12		MS24693-25	SCR, 100° Flt Hd	No. 6-32 x 5/16
25	10	10	10		MS24693-3	SCR, 100° Flt HD	No. 4-90 x 5/16
26	8	8	8		MS24693-2	SCR, 100° Flt Hd	No. 4-40 x 1/4
27	4	4	4		MS35649-244	Nut, Plain Hex	No. 4-40
28	2	2	2	91833	4725	Transistor Mtg Kit	TO-3
29	2	2	2	91833	4729	Diode Mtg Kit	DO-4
30	A/R	A/R	A/R		E-12	Wire, 19 Strd Min, Wht	MIL-W-16878/4
31	A/R	A/R	A/R		E-20	Wire, 19 Strd Min, Wht	MIL-W-16878/4
32	2	2	2		RCR07G470JM	Resistor, 47 Ω ±5%, ¼ W	MIL-R-39008/1 R1, 2
33	5	5	5		MS25036-148	Lug, Terminal	
34	A/R	A/R	A/R	Dow Corning	DC-340	Thermal Compound	
35	1	1	1		SK28956052	End Cover	
36	2	2	2		MS51957-20	Screw, Pan HD	No. 4-40 x 7/8

Parts List for P.W.A. Control Logic (A1) O/R Module

Sheet 1 of 1	Parts List			P.W.A. Control Logic (A1) O/R Module			PL21036
Item Number	Quantity Required -1	-3	-5	Code Ident No.	Part No. or Identification No.	Nomenclature or Description	Remarks
	+5	±15	+28				
1	2	2	2		CD4011AD	I.C.	U1, 3
2	1	1	1		CD4027AD	I.C.	U2
3	2	2	2		2N2222A	Transistor	Q1, 2
4	1	1	1		2N2907A	Transistor	Q3
5	1	1	1		M5757/9-038	Relay	K1
6	19	19	19		IN914B	Diode	CR1-18, 22
7	2	2	2		IN4937	Diode	CR19, 20
8	1	1	1		IN753A	Diode	CR21
9	1	1	1		M39003/01-2304	Capacitor, 6.8 µf 35 V	C1
10	3	3	3		M39014/01-1222	Capacitor, 150 pf 200V	C2, 3, 8
11	2	2	2		M39003/01-2356	Capacitor, 1 µf 50V	C4, 9
12	3	3	3		M39006/03-1060	Capacitor, 40 µf 75V	C5, 6, 7
13	1	1	1		M39014/01-1213	Capacitor, 47 pf 200V	C10
14	2	2	2		M39014/01-1237	Capacitor, 1000 pf 200V	C11, 12
15	4	4	4		RCR07G223JM	Resistor, 22K ±5%, ¼ W	R3, 4, 11, 14
16	4	4	4		RCR07G102JM	Resistor, 1K ±5%, ¼ W	R1, 6, 7, 16
17	2	2	2		RCR07G332JM	Resistor, 3.3K ±5%, ¼ W	R5, 17
18	3	3	3		RCR07G103JM	Resistor, 10K ±5%, ¼ W	22, 10, 15
19	2	2	2		RCR20G102JM	Resistor, 1K ±5%, ½ W	R8,9
20	2	2	2		RCR07G472JM	Resistor, 4.7K ±5%, ¼ W	R12, 13
21	3	3	3	Milton Ross	10109-DAP	Transipad	Use with Q1-3
22	1	1	1		21038-1	Printed Wiring Board	

P.W.A., Error Ample (A2) O/R Module

Sheet 1 of 1	Parts List			P.W.A, Error AMPL (A2) or Module			PL21040
Parts Number	Quantity Required -1	-3	-5	Code Ident No.	Part No. or Identification No.	Nomenclature or Description	Remarks
	+5	±15	+28				
1	1	1	1		LM111H	I.C.	U1
2	3	3	3		LM101AH	I.C.	U2, 3, 4
3	1	1	1	Analog	AD2700U	IOV Ref Module	U5
4	1	1	1	14925	BR567	Transformer, Current	CT1
5	5	5	5		IN914B	Diode	CR1-5
6	1	1	1	Vishay	1202-P-10K	Potentiometer, 10K ½ W	R23
7	4				M39003/01-2265	Capacitor, 220 μf 10 V	C1-4
8		4			M39003/01-2312	Capacitor, 47 μf 35 V	C1-4
9			4		M39003/01-2377	Capacitor, 15 μf 50 V	C1-4
10	1	1	1		M39014/01-1454	Capacitor, 8200 pf 100 V	C8
11	1	1	1		CMR04C050DODM	Capacitor, 5 pf 500V	C7
12	1	1	1		M39014/02-1230	Capacitor, 0.1 μf 100 V	C5
13					Deleted	Deleted	Deleted
14	1	1	1		M39014/02-1218	Capacitor, 0.01 μf 200 V	C6
15	1	1	1		RCR07G103JM	Resistor, 10K ±5%, ¼ W	R1
16	2	2	2		2CR07G470JM	Resistor, 47Ω ±5%, ¼ W	R9, 13
17	2			Vishay	5102-4.99K-±0.1%	Resistor, 4.99K ±0.1%, 0.3 W	R8, 12
18		2		Vishay	5102-15K-±0.1%	Resistor, 15K ±0.1%, 0.3 W	R8, 12
19			2	Vishay	5102-28K-±0.1%	Resistor, 28K ±0.1%, 0.3 W	R8, 12
20	2	2	2	Vishay	5102-10K-±0.1%	Resistor, 10K ±0.1%, 0.3 W	R10, 11
21	1	1	1		RMR55C4992FM	Resistor, 49.9K ±1%, 1/10 W	R7
22	1	1	1		RCR07G222JM	Resistor, 2.2K ±5%, ¼ W	R6
23	1				RNRG5C3010FM	Resistor, 301Ω ±1%, ¼ W	R2
24		1	1		RNRG5C1620FM	Resistor, 162Ω ±1%, ¼ W	R2
25	5	5	5		RNR55C1002FM	Resistor, 10K ±1%, 1/10 W	R4, 16, 21, 22, 24
26	2				RNR55C3321FM	Resistor, 3.32K ±1%, 1/10 W	R15, 17
27		2			RMR55C1002FM	Resistor, 10K ±1%, 1/10 W	R15, 17
28			2		RNR55C1962FM	Resistor, 19.6K ±1%, 1/10 W	R15, 17
29	2				RNR55C6811FM	Resistor, 6.81K ±1%, 1/10 W	R19, 20
30		2			RNR55C2052FM	Resistor, 20.5K ±1%, 1/10 W	R19, 20
31			2		RNR55C3652FM	Resistor, 36.5K ±1%, 1/10 W	R19, 20
32	2	2	2		RCR07G105JM	Resistor, 1 Meg ±5%, ¼ W	R14, 18
33	1	1	1		RCR07G471JM	Resistor, 470Ω ±5%, ¼ W	R5
34	4	4	4	Milton Ross	10198-DAP	Transipad	Use with U1-4
35	1	1	1		21042-1	Printed Wiring Board	
36	1	1	1		RNR55C5111FM	Resistor, 5.11K ±1%, 1/10 W	R3

PWA, Housekeeping Rect Filter

Sheet 1 of 1	Parts List			PWA, Housekeeping Rect Filter			PL21017
Parts Number	Quantity Required -1	-3	-5	Code Ident No.	Part No. or Identification No.	Nomenclature or Description	Remarks
1	2				21019-1	Printed Wiring Board	
2	4				2N2222A	Transistor	Q1, Q2
3	16				IN914B	Diode	CR1-4, 6-9
4	4				M5757/9-038	Relay	K1, K2
5	4				IN5354	Diode	CR5, 10
6	8				RCR07G102JM	Resistor, 1K ±5%, ¼ W	R1, 3, 4, 6
7	4				RCR07G222JM	Resistor, 2.2K ±5%, ¼ W	R2, R5
8	4				M39014/01-1219	Capacitor, 100 pf ±10%, 200 V	C2, C6
9	4				M39003/01-2304	Capacitor, 6.8 μf ±10%, 35 V	C1, C5
10	8				M39014/02-1218	Capacitor, 0.01 μf ±10%, 200 V	C3, 4, 7, 8
11	4			Milton Ross	10109-DAP	Transipad	Use with Q1, Q2

PWA, Housekeeping Reg Inverter

Sheet 1 of 1	Parts List			P.W.A, Housekeeping Reg Inverter			PL21021
Parts Number	Quantity Required -1	-3	-5	Code Ident No.	Part No. or Identification No.	Nomenclature or Description	Remarks
1	1				21023-1	Printed Wiring Board	
2	4				2N5682	Transistor	Q1, 5, 6, 7
3	1				2N2907A	Transistor	Q3
4	1				2N5680	Transistor	Q2
5	19				IN914B	Diode	CR1, 4-21
6	1				IN753A	Diode	CR2
7	1				IN821A	Diode	CR3
8	1				21056-1	Inductor, Saturable	L1
9	1				21054-1	Transformer, Signal	T1
10	3				RCR07G102JM	Resistor, 1K ±5%, ¼ W	R5, 6, 14
11	1				RCR07G103JM	Resistor, 10K ±5%, ¼ W	R1
12	1				RCR20G472JM	Resistor, 4.7K ±5%, ½ W	R3
13	1				RWR89S1R00FM	Resistor, 1Ω ±1%, 3 W	R4
14	1				RNR55C2261FM	Resistor, 2.26K ±1%, 1/10 W	R7
15	2				RCR07G330JM	Resistor, 33Ω ±5%, ¼ W	R8, R13
16	1				RCR20G182JM	Resistor, 1.8K ±5%, ½ W	R10
17	1				RNR55C4121FM	Resistor, 4.12K ±1%, 1/10 W	R11
18	1				RJR12FP102M	Potentiometer, 1K, 3/4 W	R12
19	1				RCR07G222JM	Resistor, 2.2K ±5%, ¼ W	R2
20	6				RCR07G471JM	Resistor, 470Ω, ±5%, ¼ W	R16, 17, 19, 20, 22, 23
21	3				RCR07G682JM	Resistor, 6.8K ±5%, ¼ W	R15, 18, 21
22	1				RCR20G102JM	Resistor, 1K ±5%, ½ W	R9
23	1				M39014/01-1219	Capacitor, 100 pf ±10%, 200 V	C3
24	1				M39003/01-2312	Capacitor, 47 μf ±10%, 35 V	C2
25	4				M39014/02-1218	Capacitor, 0.01 μf ±10%, 200 V	C1, 4, 5, 6
26	1				2N2222A	Transistor	Q4
27	7			Milton Ross	10109-DAP	Transipad	Use with Q1-7
28	A/R			Armstrong Company	X-81	Compound	